IN THE MATTER OF

PATENT APPLICATION

C E R T I F I C A T E

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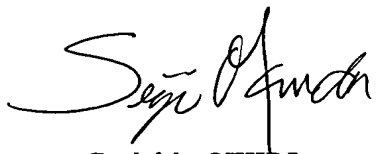
Signature 

Seiji OKUDA

(TRANSLATION)

[Name of Document] Application for Patent

[Reference Number] 2032450181

[Filing Date] July 24, 2003

[Destination] Commissioner

[International Patent Classification] G11B 7/00

[Inventor]

[Address] C/O Matsushita Electric Industrial Co., Ltd., 1006, Oaza Kadoma, Kadoma-shi, Osaka

[Name] Atsushi NAKAMURA

[Inventor]

[Address] C/O Matsushita Electric Industrial Co., Ltd., 1006, Oaza Kadoma, Kadoma-shi, Osaka

[Name] Shigeru FURUMIYA

[Applicant for Patent]

[Identification Number] 000005821

[Name] Matsushita Electric Industrial Co., Ltd.

[Agent]

[Identification Number] 100097445

[Attorney]

[Name] Fumio IWAHASHI

[Appointed Agent]

[Identification Number] 100103355

[Attorney]

[Name] Tomoyasu SAKAGUCHI

[Appointed Agent]

[Identification Number] 100109667

[Attorney]

[Name] Hiroki NAITO

[Claiming Priority Based upon an Earlier Patent Application]

[Application Number] Patent application 2003-101248

[Filing Date] April 4, 2003

[Indication of Fee]

[Reference Number of Previous Payment] 011305

[Amount of Payment] 21,000

[List of Accompanying Documents]

[Name thereof]	Claims	1
[Name thereof]	Specification	1
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[Number of General Power of Attorney] 9809938

[Name of the Document] CLAIMS

[Claim 1]

An optical recording method for writing information as edge position information, including marks and spaces of multiple different lengths, on an optical disk medium by irradiating the medium with a laser beam while changing its powers,

wherein the method is characterized by:

classifying mark lengths (code lengths) in a given write code sequence following a predetermined rule;

modulating the power of the laser beam to produce multiple pulses while making recording marks;

changing the numbers of the modulating pulses with the code length;

classifying the code lengths into at least the four groups of n, n+1, n+2 and n+3 or more, respectively, where n is a natural number representing the shortest code length; and

generating only one write pulse Pw if the code length is n, n+1 or n+2.

[Claim 2]

An optical recording method for writing information as edge position information, including marks and spaces of multiple different lengths, on an optical disk medium by irradiating the medium with a laser beam while changing its powers,

wherein the method is characterized by:

classifying mark lengths (code lengths) in a given write code sequence following a predetermined rule;

modulating the power of the laser beam to produce multiple pulses while making recording marks;

changing the numbers of the modulating pulses with the code length; and

classifying the code lengths into at least the four groups of n, n+1, n+2 and n+3 or more, respectively, where n is a natural number representing the shortest code length, and

wherein just one write pulse Pw is generated for each of n and n+1 and the widths of the write pulses for n and n+1 satisfy the inequality:

(pulse width for code length n) ≦ (pulse width for code length n+1), and

wherein two write pulses Pw are generated for each of n+2 and n+3 and the widths of the first ones of those write pulses for n+2 and n+3 satisfy the inequality:

(pulse width for code length n) ≦ (pulse width for code length n+1) and

the widths of the second ones of those write pulses for n+2 and n+3 satisfy the inequality:

(pulse width for code length n) ≦ (pulse width for code length n+1).

[Claim 3]

An optical recording method for writing information as edge position information, including marks and spaces of multiple different lengths, on an optical disk medium by irradiating the medium with a laser beam while changing its powers,

wherein the method is characterized by:

classifying mark lengths (code lengths) in a given write code sequence following a predetermined rule;

modulating the power of the laser beam to produce multiple pulses while making recording marks;

changing the numbers of the modulating pulses with the code length; and

classifying the code lengths into at least the four groups of n, n+1, n+2 and n+3 or more, respectively, where n is a natural number representing the shortest code length,

wherein in two different code lengths m and m+1 (where m is a natural number), for which the same number of write pulses Pw are generated, the widths of arbitrary K^{th} write pulses satisfy the inequality:

(pulse width for code length m) $\leqq$ (pulse width for code length m+1).

[Claim 4]

An optical recording method characterized in that in two different code lengths m and m+1, in which a bottom power level Pb is reached the same number of times between two write

pulses Pw, the widths of arbitrary K^{th} bottom pulses satisfy the inequality:

(pulse width for code length m) $\leqq$ (pulse width for code length m+1).

[Claim 5]

The optical recording method of claim 1, characterized in that the number of write pulses Pw generated to make a mark with a mark length x of n + 3 or more is the quotient obtained by dividing (x−1) by two.

[Claim 6]

The optical recording method of one of claims 1 to 4, characterized in that in a recording mark making period, an erasure power level Pe of a fundamental waveform is maintained for at least 1 Tw.

[Claim 7]

The optical recording method of one of claims 1 to 4, characterized in that in a recording mark making period, a bottom power level Pb of a fundamental waveform is maintained for at least 1 Tw.

[Claim 8]

The optical recording method of one of claims 1 to 4, characterized in that in a recording mark making period, a cooling power level Pc of a fundamental waveform is maintained for at least 1 Tw.

[Claim 9]

The optical recording method of one of claims 1 to 4,

characterized in that the start position of the first pulse and the end position of a cooling pulse are shifted in a fundamental waveform according to write code length.

[Claim 10]

The optical recording method of claim 9, characterized in that the shift is done to at least four different degrees that are defined for the code lengths of n, n+1, n+2 and n+3 or more, respectively.

[Claim 11]

An optical recorder for writing information on an optical disk medium by irradiating the medium with a laser beam while changing its powers and making marks, of which physical properties are different from those of unrecorded portions, the recorder characterized by comprising:

laser driver means for modulating the power of the laser beam;

coding means for transforming the information into a write code sequence; and

mark length classifying means for changing the numbers of pulses to generate in a mark making period in order to modulate the power of the laser beam according to mark length (or code length) in the write code sequence,

wherein the mark length classifying means classifies the code lengths into at least the four groups of n, n+1, n+2 and n+3 or more, respectively, where n is a natural number representing the shortest code length, and

wherein the driver means drives a laser so as to generate only one write pulse Pw if the code length is n, n+1 or n+2. [Claim 12]

An optical recorder for writing information on an optical disk medium by irradiating the medium with a laser beam while changing its powers and making marks, of which physical properties are different from those of unrecorded portions, the recorder characterized by comprising:

laser driver means for modulating the power of the laser beam;

coding means for transforming the information into a write code sequence; and

mark length classifying means for changing the numbers of pulses to generate in a mark making period in order to modulate the power of the laser beam according to mark length (or code length) in the write code sequence,

wherein the mark length classifying means classifies the code lengths into at least the four groups of n, n+1, n+2 and n+3 or more, respectively, where n is a natural number representing the shortest code length, and

wherein the driver means drives the laser such that just one write pulse Pw is generated for each of n and n+1 and the widths of the write pulses for n and n+1 satisfy the inequality:

(pulse width for code length n) $\leqq$ (pulse width for code length n+1), and

that two write pulses Pw are generated for each of n+2 and n+3 and the widths of the first ones of those write pulses for n+2 and n+3 satisfy the inequality:

(pulse width for code length n) ≦ (pulse width for code length n+1) and

the widths of the second ones of those write pulses for n+2 and n+3 satisfy the inequality:

(pulse width for code length n) ≦ (pulse width for code length n+1).

[Claim 13]

An optical recorder for writing information as edge position information, including marks and spaces of multiple different lengths, on an optical disk medium by irradiating the medium with a laser beam while changing its powers, the recorder characterized by comprising:

laser driver means for modulating the power of the laser beam;

coding means for transforming the information into a write code sequence; and

mark length classifying means for changing the numbers of pulses to generate in a mark making period in order to modulate the power of the laser beam according to mark length (or code length) in the write code sequence,

wherein the mark length classifying means classifies the code lengths into at least the four groups of n, n+1, n+2

and n + 3 or more, respectively, where n is a natural number representing the shortest code length, and

wherein the driver means drives the laser such that in two different code lengths m and m+1 (where m is a natural number), for which the same number of write pulses Pw are generated, the widths of arbitrary K^{th} write pulses satisfy the inequality:

(pulse width for code length m) ≦ (pulse width for code length m+1).

[Claim 14]

An optical recorder characterized in that in two different code lengths m and m+1, in which a bottom power level Pb is reached the same number of times between two write pulses Pw, the widths of arbitrary K^{th} bottom pulses satisfy the inequality:

(pulse width for code length m) ≦ (pulse width for code length m+1).

[Claim 15]

The optical recorder of claim 11, characterized in that the driver means drives the laser such that the number of write pulses generated to make a mark with a code length x of n + 3 or more is the quotient obtained by dividing (x − 1) by two.

[Claim 16]

The optical recorder of one of claims 11 to 14, characterized in that the laser driver means is designed such

that every interval between trailing and leading edges of two laser pulses in a fundamental waveform in the mark making period becomes at least equal to a detection window width Tw.

[Claim 17]

The optical recorder of one of claims 11 to 14, characterized by further comprising pulse shifting means for shifting the start position of the first pulse and the end position of a cooling pulse according to write code length.

[Claim 18]

The optical recorder of one of claims 11 to 14, characterized by further comprising pulse shifting means for shifting the start position of the first pulse and the end position of the last pulse according to write code length.

[Claim 19]

The optical recorder of one of claims 11 to 14, characterized by further comprising write compensation means for shifting the positions to at least four different degrees that are defined for the code lengths of n, n+1, n+2 and n+3 or more, respectively.

[Name of the Document] DESCRIPTION

[Title of the Invention] Method and apparatus for performing optical recording on optical disk medium

[Field of the Invention]

[0001]

The present invention relates to an optical recording method and an optical disk recorder for writing information on an optical disk medium by irradiating the medium with a laser beam and making a mark with a different physical property from a non-recorded portion thereof.

[Background Art]

[0002]

A DVD-RAM or any other optical disk of a similar type is a phase change disk that makes a mark as an amorphous area on a recording film thereof by irradiating it with a laser beam and controlling the power of the laser beam during heating such that the recording film will cool at variable rates. To increase the information transfer rate while information is being read from, or written on, any of those optical disk media, either the recording linear density or the scanning rate of the beam spot on the storage medium may be increased. In order to increase the recording linear density, it is effective to reduce the mark length and space length or to narrow the mark edge position detecting interval by reducing the steps of variations in mark and space lengths. However, if the recording linear density were increased, then the SNR of the read signal would pose a problem. In that case, a

significant increase in recording linear density should not be expected.

[0003]

To make very small marks on an optical disk with high precision, according to a first conventional technique, a write waveform corresponding to a mark making period is defined as a train of pulses representing the length of a mark (i.e., the length of code) in a write code sequence, and the number and amplitudes of those pulses are controlled according to the length of the write code sequence (see Patent Document No. 1, for example). The write waveform during the mark making period can be divided into a top portion and a succeeding portion. The respective pulses generally have different pulse heights. Also, in non-mark making periods of the write waveform, a write auxiliary pulse is generated to follow the space. Thus, according to this first conventional technique disclosed in the publication cited above, the diffusion of heat from a preceding mark toward the front edge of the very next mark can be compensated for, and the mark width and mark edge position can be controlled with high precision, irrespective of the space length.

[0004]

According to a second conventional technique, each write code is broken down into a plurality of primitive elements with multiple different lengths such that a single write pulse is assigned to each of those elements. And each write

code is defined as a series of independent recording marks associated with multiple write pulses (see Patent Document No. 2, for example).

[0005]

A third conventional technique adopts a multi-pulse writing method that uses the first heating pulse, a number of succeeding heating and cooling pulses that follow the first pulse, and the last cooling pulse. According to the third conventional technique, in recording a mark, of which the length is either an odd number of times or an even number of times as long as one period of a write channel clock, the pulse width of the succeeding heating and cooling pulses is made nearly equal to the length of one period of the write channel clock (see Patent Document No. 3, for example).

[0006]

According to a fourth conventional technique, the energy and the number of pulses that are applied while a mark of an arbitrary length is being made are changed according to the length of the mark in a write code sequence such that the gap between two arbitrary variation points of the energy applied per unit time during the mark making period becomes longer than a half of the detection window width (see Patent Document No. 4).

[Patent Document No. 1]

Japanese Patent Application Laid-Open Publication No. 5-298737

[Patent Document No. 2]

Japanese Patent Application Laid-Open Publication No. 8-7277

[Patent Document No. 3]

Japanese Patent Application Laid-Open Publication No. 9-134525

[Patent Document No. 4]

Japanese Patent Application Laid-Open Publication No. 11-175976

[Disclosure of invention]

[Problems to Be Solved by the Invention]

[0007]

According to the first conventional technique, the length of a mark, corresponding with the detection window width, is associated with one shot of write pulse. Thus, if the detection window width is shortened, then the semiconductor laser diode, functioning as a source of generating write energy, needs to be driven faster than usual. For example, if one tries to realize a burst transfer rate of 10 megabytes per second, which is almost as high as that of a magnetic disk drive, by a normal (1, 7) modulation technique, then the detection window width of the read signal will be about 8.3 ns and therefore the shortest write current pulse width will be about 4.2 ns, which is approximately a half as long as the detection window width. However, it usually takes several nanoseconds to activate a semiconductor laser, and it is difficult to generate a write beam pulse accurately. Also, even if a write beam pulse could be generated accurately,

normal marks could not be made in a situation where multi-pulse writing is carried out on a medium such as a phase change disk in which the mark making is controlled by the cooling rate of its heated portion. This is because the next beam pulse is radiated before the heated portion is cooled sufficiently. Also, if one tries to realize a burst transfer rate of 10 megabytes per second by the (1, 7) modulation technique, for example, then the amount of time it takes to cool the storage medium will also be about 4.2 ns, which is equal to the shortest write current pulse width. Consequently, marks could not be made properly depending on the property of the storage medium.

[0008]

According to the second conventional technique mentioned above, each write code is broken down into a plurality of primitive elements with multiple different lengths such that a single write pulse is assigned to each of those elements and that each write code is defined as a series of respectively independent recording marks associated with write pulses. However, this conventional technique does not consider thermal balance between write pulses for respective elements at all. That is why as the recording linear density is increased, it becomes more and more difficult to control the mark edge position. That is to say, in making marks that will form a single write code, the recording marks will have variable widths from one position to another because the quantity of heat accumulated in the recording layer for the

top portion of the write code is different from that of heat accumulated there for the terminal portion of the write code. As a result, the edge recording cannot be carried out as intended.

[0009]

In the third conventional technique, a pulse, which is much shorter than the detection window width, may be inserted into the write waveform approximately in the middle of the mark making period, and the mark width changes significantly around there compared to the other portions. According to the document disclosing this conventional technique, when a mark edge recording operation is carried out, the variation in signal amplitude around the center portion of a mark should pose no serious problem as long as the mark edge position is accurate. In a read/write drive that determines read/write conditions by detecting the average level of a read signal, however, such distortion of the read signal should affect the operation of the drive. As to a phase change storage medium, for example, a signal can be detected as a variation in reflectance just like a phase pit type storage medium. That is why the phase change storage medium and phase pit type storage medium can easily share the same read drive in common. However, since the read signal of the phase pit type storage medium has no such distortion, it is actually difficult to read the phase change storage medium and phase pit type storage medium using the same drive.

[0010]

Also, according to the fourth conventional technique, the write power level of the write pulse train changes stepwise, thus requiring complicated power control. Also, in writing a signal with a code length of 4 Tw, the laser beam needs to be emitted so as to achieve a higher power level than the average one at least for a period of time corresponding to 3 Tw. When a very small mark needs to be made on a high-density storage medium in the near future, such an emission time will be too long to make desired recording marks.

[0011]

As can be seen, none of the conventional techniques mentioned above can contribute to making marks sufficiently accurately when the transfer rate is high or achieving sufficiently high density on the storage layer with good reliability.

[Means for Solving the Problems]

[0012]

To perform read/write operations with high reliability by making marks with good stability, a write waveform that will not cause any of those problems needs to be selected. Besides contributing to making marks with high accuracy, the write waveform should satisfy the following two requirements. Firstly, the write waveform should make it easy to drive a semiconductor laser as a light source. Secondly, the write waveform should allow the given storage medium ample time for cooling.

[0013]

Thus, in order to overcome the problems described above, the present invention provides an optical recording method as a method for writing information as edge position information, including marks and spaces of multiple different lengths, on an optical disk medium by irradiating the medium with a laser beam while changing its powers. The method is characterized by: classifying mark lengths (code lengths) in a given write code sequence following a predetermined rule; modulating the power of the laser beam to produce multiple pulses while making recording marks; changing the numbers of the modulating pulses with the code length; classifying the code lengths into at least the four groups of n, n+1, n+2 and n+3 or more, respectively, where n is a natural number representing the shortest code length; and generating only one write pulse Pw if the code length is n, n+1 or n+2.

[0014]

Another optical recording method according to the present invention is a method for writing information as edge position information, including marks and spaces of multiple different lengths, on an optical disk medium by irradiating the medium with a laser beam while changing its powers. The method is characterized by: classifying mark lengths (code lengths) in a given write code sequence following a predetermined rule; modulating the power of the laser beam to produce multiple pulses while making recording marks; changing the numbers of the modulating pulses with the code

length; and classifying the code lengths into at least the four groups of n, n+1, n+2 and n+3 or more, respectively, where n is a natural number representing the shortest code length. Just one write pulse Pw is generated for each of n and n+1 and the widths of the write pulses for n and n+1 satisfy the inequality: (pulse width for code length n) ≦ (pulse width for code length n+1). Two write pulses Pw are generated for each of n+2 and n+3 and the widths of the first ones of those write pulses for n+2 and n+3 satisfy the inequality: (pulse width for code length n) ≦ (pulse width for code length n+1). And the widths of the second ones of those write pulses for n+2 and n+3 satisfy the inequality: (pulse width for code length n) ≦ (pulse width for code length n+1).

[0015]

Still another optical recording method according to the present invention is a method for writing information as edge position information, including marks and spaces of multiple different lengths, on an optical disk medium by irradiating the medium with a laser beam while changing its powers. The method is characterized by: classifying mark lengths (code lengths) in a given write code sequence following a predetermined rule; modulating the power of the laser beam to produce multiple pulses while making recording marks; changing the numbers of the modulating pulses with the code length; and classifying the code lengths into at least the four groups of n, n+1, n+2 and n+3 or more, respectively, where n is a natural number representing the shortest code

length. The method is characterized in that in two different code lengths m and m+1 (where m is a natural number), for which the same number of write pulses Pw are generated, the widths of arbitrary K^{th} write pulses satisfy the inequality: (pulse width for code length m) ≦ (pulse width for code length m+1).

[0016]

The optical recording method of the present invention is also characterized in that in two different code lengths m and m+1, in which a bottom power level Pb is reached the same number of times between two write pulses Pw, the widths of arbitrary K^{th} bottom pulses satisfy the inequality: (pulse width for code length m) ≦ (pulse width for code length m+1).

[0017]

The optical recording method of the present invention is further characterized in that the number of write pulses Pw generated to make a mark with a mark length x of n+3 or more is the quotient obtained by dividing (x−1) by two.

[0018]

The optical recording method of the present invention is further characterized in that in a recording mark making period, an erasure power level Pe of a fundamental waveform is maintained for at least 1 Tw.

[0019]

The optical recording method of the present invention is further characterized in that in a recording mark making

period, a bottom power level Pb of a fundamental waveform is maintained for at least 1 Tw.

[0020]

The optical recording method of the present invention is further characterized in that in a recording mark making period, a cooling power level Pc of a fundamental waveform is maintained for at least 1 Tw.

[0021]

The optical recording method of the present invention is further characterized in that the start position of the first pulse and the end position of a cooling pulse are shifted in a fundamental waveform according to write code length.

[0022]

The optical recording method of the present invention is further characterized in that the shift is done to at least four different degrees that are defined for the code lengths of n, n+1, n+2 and n+3 or more, respectively.

[0023]

An optical recorder according to the present invention is designed to write information on an optical disk medium by irradiating the medium with a laser beam while changing its powers and making marks, of which physical properties are different from those of unrecorded portions. The recorder is characterized by including: laser driver means for modulating the power of the laser beam; coding means for transforming the information into a write code sequence; and mark length classifying means for changing the numbers of pulses to

generate in a mark making period in order to modulate the power of the laser beam according to mark length (or code length) in the write code sequence. The mark length classifying means classifies the code lengths into at least the four groups of n, n + 1, n + 2 and n + 3 or more, respectively, where n is a natural number representing the shortest code length. The driver means drives a laser so as to generate only one write pulse Pw if the code length is n, n +1 or n+2.

[0024]

Another optical recorder according to the present invention is designed to write information on an optical disk medium by irradiating the medium with a laser beam while changing its powers and making marks, of which physical properties are different from those of unrecorded portions. The recorder is characterized by including: laser driver means for modulating the power of the laser beam; coding means for transforming the information into a write code sequence; and mark length classifying means for changing the numbers of pulses to generate in a mark making period in order to modulate the power of the laser beam according to mark length (or code length) in the write code sequence. The mark length classifying means classifies the code lengths into at least the four groups of n, n + 1, n + 2 and n + 3 or more, respectively, where n is a natural number representing the shortest code length. The driver means drives the laser such that just one write pulse Pw is generated for each of n and

n+1 and the widths of the write pulses for n and n+1 satisfy the inequality: (pulse width for code length n) ≦ (pulse width for code length n + 1), and that two write pulses Pw are generated for each of n+2 and n+3 and the widths of the first ones of those write pulses for n+2 and n+3 satisfy the inequality: (pulse width for code length n) ≦ (pulse width for code length n + 1) and the widths of the second ones of those write pulses for n+2 and n+3 satisfy the inequality: (pulse width for code length n) ≦ (pulse width for code length n+1).

[0025]

Still another optical recorder according to the present invention is designed to write information as edge position information, including marks and spaces of multiple different lengths, on an optical disk medium by irradiating the medium with a laser beam while changing its powers. The recorder is characterized by including: laser driver means for modulating the power of the laser beam; coding means for transforming the information into a write code sequence; and mark length classifying means for changing the numbers of pulses to generate in a mark making period in order to modulate the power of the laser beam according to mark length (or code length) in the write code sequence. The mark length classifying means classifies the code lengths into at least the four groups of n, n + 1, n + 2 and n + 3 or more, respectively, where n is a natural number representing the shortest code length. The driver means drives the laser such that in two different code lengths m and m+1 (where m is a

natural number), for which the same number of write pulses Pw are generated, the widths of arbitrary K^{th} write pulses satisfy the inequality: (pulse width for code length m) ≦ (pulse width for code length m+1).

[0026]

Yet another optical recorder according to the present invention is characterized in that in two different code lengths m and m+1, in which a bottom power level Pb is reached the same number of times between two write pulses Pw, the widths of arbitrary K^{th} bottom pulses satisfy the inequality: (pulse width for code length m) ≦ (pulse width for code length m+1).

[0027]

The optical recorder of the present invention is also characterized in that the driver means drives the laser such that the number of write pulses generated to make a mark with a code length x of n+3 or more is the quotient obtained by dividing (x−1) by two. The optical recorder of the present invention is further characterized in that the laser driver means is designed such that every interval between trailing and leading edges of two laser pulses in a fundamental waveform in the mark making period becomes at least equal to a detection window width Tw.

[0028]

The optical recorder of the present invention is further characterized by further including pulse shifting means for

shifting the start position of the first pulse and the end position of a cooling pulse according to write code length.

[0029]

The optical recorder of the present invention is further characterized by further including pulse shifting means for shifting the start position of the first pulse and the end position of the last pulse according to write code length.

[0030]

The optical recorder of the present invention is further characterized by further including write compensation means for shifting the positions to at least four different degrees that are defined for the code lengths of n, n+1, n+2 and n+3 or more, respectively.

[Effect of the Invention]

[0031]

According to the present invention, an apparatus for writing information on a storage medium by applying energy to the storage medium and making marks that have a different physical property from the non-recorded portion thereof can make those marks quickly and accurately. As a result, the mark edge recording technique, which will effectively contribute to increasing the recording linear density, can be adopted as the method of recording. Consequently, the read/write operations can be done more quickly and with more reliability, and yet the sizes of the apparatus for writing information and the storage medium can be reduced as well. That is why the present invention is very cost-effective.

[Best Mode for Carrying Out the Invention]

[0032]

Hereinafter, preferred embodiments of the present invention will be described. In the following description of preferred embodiments, a phase change optical disk is used as a storage medium. However, the storage media that may be used in the present invention are not necessarily limited to that type. Rather the technique of the present invention is commonly applicable to any other type of storage medium on which information is written by making a "mark" with a different physical property from the non-recorded portions with some energy applied to the storage medium.

[0033]

In the following description of preferred embodiments, the "write energy level" means the average energy level of a laser beam in a period of time that is approximately a half as long as the detection window width (which is a unit of variation in the edge position of marks and spaces). If a frequency component that is much higher than the frequency of a period corresponding to the detection window width is superposed on a write waveform for some reason (e.g., to minimize laser noise), then the "write energy level" means an average energy level of a period of time that is long enough to neglect the influence of that frequency component.

[0034]

FIG. **1** illustrates an overall configuration for an optical recorder according to the present invention. The

coder **113** receives write data **127** to be written and converts it into a write code sequence (NRZI) **126** representing the marks and spaces to be made on an optical disk **117.** The write code sequence **126** is sent to a write waveform generator **112,** where the sequence **126** is converted into a level producing signal **125** corresponding to the write pulse waveform. The coder **113** and write waveform generator **112** operate in response to a reference clock signal **128** generated by a reference clock generator **119.** The level producing signal **125** is passed to a pulse shifter, which compensates for the pulsed waveform of the level generating signal **125** on the time axis in accordance with a write compensation table value of a write compensator **118,** thereby generating a pulse generation signal **130** and forwarding it to a laser driver **111.**

[0035]

The laser driver **111** generates a laser drive current **124** responsive to the pulse generation signal **130,** thereby causing a laser **110** to emit a laser beam in accordance with a predetermined write pulse waveform. The laser beam **123** emitted from the laser **110** passes a collimator lens **109,** a half mirror **108** and an objective lens **116** and then is condensed onto an optical disk **117.** The condensed pulsed laser beam **123** heats a portion the recording film, thereby leaving marks and spaces there. In reading information, the rows of marks on the optical disk **117** are scanned with the laser beam **123** with a power level that is low enough to avoid destroying the marks. The light that has been reflected from the optical disk **117**

passes the objective lens **116** and half mirror **108** and then enters a detector lens **106.** Then the laser beam passes the detector lens **106** and then is condensed on a photodetector **100.** According to the light intensity distribution on its photosensitive plane, the photodetector **100** converts the incoming light into an electrical signal. This electrical signal is amplified by a pre-amplifier **101** provided for each division of the photodetector **100,** thereby generating a read signal **120** that indicates whether or not there is a mark at the scan point on the optical disk **117.** The read signal **120** is subjected by a waveform equalizer **103** to a waveform equalization process and then converted by a binarizer **104** into a binarized read signal **121.** A decoder **105** further converts this binarized read signal **121** in the opposite way to the coder **113,** thereby generating read data **122.** In this preferred embodiment, the reference clock signal has a frequency of 132 MHz and a Tw of 7.58 ns. Also, in this preferred embodiment, the laser may be a semiconductor laser that oscillates at a wavelength of 405 nm and the objective lens may have an NA of 0.85, for example. The optical disk medium may be either a single-layer disk that has only one information storage layer or a dual-layer disk that has two information storage layers. Also, the optical disk may be either a rewritable optical disk medium that uses a phase change recording material or a write-once optical disk that allows the user to write data there only once. The coding method does not have to be the (1, 7) modulation but may also

be a 17 PP modulation or an 8-16 modulation. The 8-16 modulation has the shortest code length of 3 T. In that case, an extra length of one may be added to the code length of this preferred embodiment that uses the (1, 7) modulation.

[0036]

FIG. **2** illustrates an exemplary detailed configuration for the write processing system **129** of the present invention shown in FIG. **1**. The write data **127** is converted by the coder **113** into the write code sequence **126** representing mark lengths, space lengths, and information about their top positions. The write code sequence **126** is transmitted to a mark length classifier **201** and a write waveform table **202**. The mark length classifier **201** classifies the mark lengths of the write code sequence **126** following a predetermined rule and gives the results as a mark length classification signal **204** to the write waveform table **202**. The counter **200** refers to the write code sequence **126** and measures the length of time from a mark top position responsive to the reference clock signal **128**, thereby generating a count signal **205**. In accordance with the write code sequence **126**, mark length classification signal **204** and count signal **205**, the write waveform table **202** outputs the level producing signal **125**, reflecting a predetermined write pulse waveform, to the pulse shifter **115**. The pulsed waveform of the level producing signal **125** is compensated for on the time axis according to the write compensation table value of the write compensator **118** and then sent out as the pulse generation signal **130** to

the laser driver **111**. Responsive to the pulse generation signal **130**, the laser driver **111** drives the laser **110**.

[0037]

Portions **(a)** through **(h)** of FIG. **3** show the marks and spaces of write code sequences for a conventional apparatus and the apparatus of the present invention and also show an exemplary operation of generating a write waveform to leave such marks and spaces. In some cases, the length or level of a portion of the write pulse waveform needs to be finely adjusted (i.e., write compensation needs to be carried out) in a certain period for some reason by reference to the preceding and succeeding write patterns and code lengths. In the following description of the write pulse waveform, when such write compensation is carried out, the write pulse waveform is supposed to be compared to the original one yet to be finely adjusted. For that reason, the write pulse waveform will be described on the supposition that the write pattern remains the same over a rather long distance before and after the mark to be made. As used herein, the "rather long distance" means a distance that is much longer than the distance on a medium to be affected by the application of the write energy for a period of time approximately corresponding to the detection window width. Portion **(a)** of FIG. **3** shows the reference clock signal **128** that is used as a time reference for a write operation. Tw denotes one clock period. Portion **(b)** of FIG. **3** shows the write code sequence **126** obtained by getting the write data subjected to the NRZI conversion by the coder **113**.

In portion **(b)** of FIG. **3**, Tw denotes the detection window width, which is the minimum unit of variation in the mark or space length in the write code sequence **126**. Portion **(c)** of FIG. **3** schematically illustrates marks and spaces to be actually recorded on the optical disk. The beam spot of the laser beam shifts from the left to the right in portion **(c)** of FIG. **3**. The mark **301** is made so as to represent level "1" in the write code sequence **126**. The length of the mark **301** is proportional to that of the period that has level "1" in the write code sequence **126**. Portion **(d)** of FIG. **3** shows the count signal **205** according to the present invention, in which the amount of time that has passed since the top of the mark **301** or space **302** is measured on a Tw basis. Portion **(e)** of FIG. **3** shows a mark length classification signal **307** in a conventional apparatus. In this conventional apparatus, the mark lengths are classified into odd-number-of-times longer ones and even-number-of-times longer ones. Portion **(g)** of FIG. **3** shows the mark length classification signal **204** of the present invention. In this preferred embodiment, the mark lengths are classified into the shortest code length of 2T, the second shortest code length of 3T, the third shortest code length of 4T, and the fourth shortest or less short code lengths, which are further classified into odd-number-of-times longer code lengths and even-number-of-times longer code lengths.

[0038]

Portions **(f)** and **(h)** of FIG. **3** show write waveforms for

the conventional and inventive apparatuses, respectively, and are the counterparts of the write code sequence **126** shown in portion **(b)** of FIG. **3**. These write waveforms **303** and **304** are generated by reference to the count signal **205** and write code sequence **126**. The conventional apparatus further refers to the mark length classification signal **307** in addition to those signals. On the other hand, the apparatus of the present invention refers to not only those signals but also the mark length classification signal **204** as well.

[0039]

In the apparatus of the present invention, the cooling time of the write pulse waveform **304** is never shorter than 1 Tw.

[0040]

Hereinafter, exemplary write waveforms **500** through **506** for the conventional apparatus will be described with reference to portions **(a)** through **(j)** of FIG. **5**. The coder **113** is supposed to adopt a coding method in which every (1, 7) modulated code is always subjected to the NRZI modulation. For that reason, the mark and space lengths always fall within the range of 2 Tw through 8 Tw.

[0041]

FIG. **10** illustrates a configuration for the write processing system of the conventional apparatus.

[0042]

The mark length classifier **1001** shown in FIG. **10** divides the code length by the divisor of two (i.e., performs a

remainder calculation). This mark length classifier classifies the marks and spaces of the write code sequence into ones of which the lengths are even numbers of times as long as the detection window width Tw and ones of which the lengths are odd numbers of times as long as the detection window width Tw.

[0043]

Portion **(b)** of FIG. **5** shows the count signal **1005** generated by the counter **1000**, which measures the length of time from a mark top position on a detection window width Tw basis. The time at which the count signal goes zero corresponds to the top of a mark or space.

[0044]

Portion **(c)** of FIG. **5** shows a write pulse waveform while a mark with the 2 Tw length is being made. The mark making period **305** includes a pulse with a length of 1 Tw and a level Pw1. The non-mark-making period begins with a period with a length of 1 Tw and a level Pb and then maintains a level Pa until the next mark making period. Portion **(e)** of FIG. **5** shows a write pulse waveform while a mark with the 4 Tw length is being made. The mark making period **305** includes a pulse with the same length of 1 Tw and the same level Pw1 as the counterpart shown in portion **(c)** of FIG. **5**, which is followed by a period with a length of 1 Tw and a level Pa and then a period with a length of 1 Tw and a level Pw3. After that, as shown in portions **(g)** and **(i)** of FIG. **5**, in making a mark of which the length is an even number of times as long as the detection window width Tw, a period with a length of 1 Tw and

a level Pa and another period with a length of 1 Tw and a level Pw3 are added per mark length of 2 Tw to the end of the mark making period. Portion **(d)** of FIG. **5** shows a write pulse waveform while a mark with the 3 Tw length is being made. The mark making period **305** includes a pulse with the same length of 1 Tw and the same level Pw1 as the counterpart shown in portion **(c)** of FIG. **5**, which is followed by a period with a length of 1 Tw and a level Pw2. After that, as shown in portions **(f)** and **(h)** of FIG. **5**, in making a mark of which the length is an odd number of times as long as the detection window width Tw, a period with a length of 1 Tw and a level Pa and another period with a length of 1 Tw and a level Pw3 are added per mark length of 2 Tw to the end of the mark making period. The non-mark-making period begins with a period with a length of 1 Tw and a level Pb irrespective of the space length and then maintains the level Pa until the next mark making period. In the conventional write pulse waveform, the shortest cooling period in the mark making period **305** has a length of 1 Tw.

[0045]

FIG. **4** shows write pulse waveforms **400** through **407** according to the present invention. In this preferred embodiment, the coder **113** adopts a coding method in which the (1, 7) code modulation is followed by the NRZI modulation, and each and every mark or space length falls within the range of 2 Tw to 8 Tw. This coding method is also applicable to even a situation where a signal of 9 Tw, for example, is

intentionally inserted as a sync signal. However, this does not amend the coding rule of the coder **113**. Rather, the present invention is applicable for use in the coder **113** that complies with any arbitrary coding rule (e.g., 8-16 modulation). The mark length classifier **201** shown in FIG. **2** classifies the code lengths of the marks to be made into the four groups of 2T, 3T, 4T and 5T or more. If the code length **n** is 5T or more, the mark length classifier **201** divides (n-1) by the divisor of two (i.e., performs a remainder calculation). By using such a mark length classification signal, the marks and spaces of the write code sequence can be classified into ones that are even-number-of-times as long as the detection window width **Tw** and ones that are odd-number-of-times as long as the detection window width **Tw**. In this preferred embodiment, the divisor is supposed to be two for the sake of simplicity. However, this does not impose any limitation on how to classify the mark lengths. Thus, three or any other greater divisor may be used instead. Also, the mark length classifier **201** of this preferred embodiment operates so as to perform a remainder calculation. However, this never put any limitation on the structure or operation of the mark length classifier **201** but any other classification method may also be adopted.

[0046]

Portion **(b)** of FIG. **4** shows the count signal **205** generated by the counter **200**. The amount of time that has passed since the top of a mark is counted on a detection

window width (Tw) basis. The time at which the count signal goes zero corresponds to the top of a mark or space.

[0047]

Portion **(c)** of FIG. **4** shows a write pulse waveform in making a mark with the 2 Tw length. In this case, the mark making period **305** consists of a single pulse with a length of 0.5 Tw to 1 Tw and a level Pw.

[0048]

Portion **(d)** of FIG. **4** shows a write pulse waveform in making a mark with the 3 Tw length. In this case, the mark making period **305** consists of a single pulse with a length of 1 Tw to less than 2 Tw and a level Pw. It should be noted that in this case, the mark making period is supposed to be longer than that of the 2 Tw long one by at least 0.5 Tw.

[0049]

Portion **(e)** of FIG. **4** shows a write pulse waveform in making a mark with the 4 Tw length. In this case, the mark making period **305** consists of a single pulse with a length of 1.5 Tw to less than 2.5 Tw and a level Pw. It should be noted that in this case, the mark making period is supposed to be longer than that of the 3 Tw long one by at least 0.5 Tw.

[0050]

Portion **(f)** of FIG. **4** shows a write pulse waveform in making a mark with the 5 Tw length. In this case, the mark making period **305** includes a pulse with a length of 1 TTw and a level Pw, which is followed by a period with a length of 1 Tw and a level Pe and then a period with a length of 1 Tw and

a level Pw.

[0051]

After that, in making a mark that is an odd number of times as long as the detection window width Tw, the write pulse waveform during the mark making period includes an additional period with a length of 1 Tw and a level Pe and another additional period with a length of 1 Tw and a level Pw per mark length of 2 Tw in the middle of the mark making period as shown in portions **(h)** and **(j)** of FIG. **4**.

[0052]

Portion **(g)** of FIG. **4** shows a write pulse waveform in making a mark with the 6 Tw length. In this case, the mark making period **305** includes a pulse with a length of 1 TTw and a level Pw, which is followed by a period with a length of 2 Tw and a level Pe and then a period with a length of 1 Tw and a level Pw.

[0053]

After that, in making a mark that is an even number of times as long as the detection window width Tw, the write pulse waveform during the mark making period includes an additional period with a length of 1 Tw and a level Pe and another additional period with a length of 1 Tw and a level Pw per mark length of 2 Tw in the middle of the mark making period as shown in portion **(i)** of FIG. **4**.

[0054]

In a non-mark-making period, the level of the signal waveform is maintained at Pe until the next mark making

period irrespective of the space length. In this preferred embodiment, the shortest Pe level period (i.e., the shortest cooling period) during the mark making period **305** has a length of 1 Tw.

[0055]

As used herein, the "mark making period" refers to the interval between the leading edge of the first pulse and the trailing edge of the last pulse.

[0056]

Next, FIG. **6** shows write pulse waveforms **600** through **607** according to the present invention. In this preferred embodiment, the coder **113** also adopts the coding method in which the (1, 7) code modulation is followed by the NRZI modulation as in portions **(a)** through **(j)** of FIG. **4**, and each and every mark or space length falls within the range of 2 Tw to 8 Tw. This coding method is also applicable to even a situation where a signal of 9 Tw, for example, is intentionally inserted as a sync signal. The mark length classifier **201** shown in FIG. **2** classifies the code lengths of the marks to be made into the four groups of 2T, 3T, 4T and 5T or more. If the code length **n** is 5T or more, the mark length classifier **201** divides (n-1) by the divisor of two (i.e., performs a remainder calculation). By using such a mark length classification signal, the marks and spaces of the write code sequence can be classified into ones that are even-number-of-times as long as the detection window width **Tw** and ones that are odd-number-of-times as long as the detection

window width **Tw**. In this preferred embodiment, the divisor is supposed to be two for the sake of simplicity. However, this does not impose any limitation on how to classify the mark lengths. Thus, three or any other greater divisor may be used instead. Also, the mark length classifier **201** of this preferred embodiment operates so as to perform a remainder calculation. However, this never put any limitation on the structure or operation of the mark length classifier **201** but any other classification method may also be adopted.

[0057]

Portion **(b)** of FIG. **6** shows the count signal **205** generated by the counter **200**. The amount of time that has passed since the top of a mark is counted on a detection window width (Tw) basis. The time at which the count signal goes zero corresponds to the top of a mark or space.

[0058]

Portion **(c)** of FIG. **6** shows a write pulse waveform in making a mark with the 2 Tw length. In this case, the mark making period **305** consists of a single pulse with a length of 0.5 Tw to 1 Tw and a level Pw.

[0059]

Portion **(d)** of FIG. **6** shows a write pulse waveform in making a mark with the 3 Tw length. In this case, the mark making period **305** consists of a single pulse with a length of 1 Tw to less than 2 Tw and a level Pw. It should be noted that in this case, the mark making period is supposed to be longer than that of the 2 Tw long one by at least 0.5 Tw.

[0060]

Portion **(e)** of FIG. **6** shows a write pulse waveform in making a mark with the 4 Tw length. In this case, the mark making period **305** consists of a single pulse with a length of 1.5 Tw to less than 2.5 Tw and a level Pw. It should be noted that in this case, the mark making period is supposed to be longer than that of the 3 Tw long one by at least 0.5 Tw.

[0061]

Portion **(f)** of FIG. **6** shows a write pulse waveform in making a mark with the 5 Tw length. In this case, the mark making period **305** includes a pulse with a length of 1 TTw and a level Pw, which is followed by a period with a length of 1 Tw and a level Pb and then a period with a length of 1 Tw and a level Pw.

[0062]

After that, in making a mark that is an odd number of times as long as the detection window width Tw, the write pulse waveform during the mark making period includes an additional period with a length of 1 Tw and a level Pb and another additional period with a length of 1 Tw and a level Pw per mark length of 2 Tw in the middle of the mark making period as shown in portions **(h)** and **(j)** of FIG. **6**.

[0063]

Portion **(g)** of FIG. **6** shows a write pulse waveform in making a mark with the 6 Tw length. In this case, the mark making period **305** includes a pulse with a length of 1 Tw and a level Pw, which is followed by a period with a length of 2 Tw

and a level Pb and then a period with a length of 1 Tw and a level Pw.

[0064]

After that, in making a mark that is an even number of times as long as the detection window width Tw, the write pulse waveform during the mark making period includes an additional period with a length of 1 Tw and a level Pb and another additional period with a length of 1 Tw and a level Pw per mark length of 2 Tw in the middle of the mark making period as shown in portion **(i)** of FIG. **6**.

[0065]

In a non-mark-making period, the level of the signal waveform is maintained at Pe until the next mark making period irrespective of the space length. In this preferred embodiment, the shortest Pb level period (i.e., the shortest cooling period) during the mark making period **305** has a length of 1 Tw.

[0066]

As used herein, the "mark making period" refers to the interval between the leading edge of the first pulse and the trailing edge of the last pulse.

[0067]

Next, FIG. **7** shows write pulse waveforms **700** through **707** according to the present invention. In this preferred embodiment, the coder **113** also adopts the coding method in which the (1, 7) code modulation is followed by the NRZI modulation as in portions **(a)** through **(j)** of FIG. **4**, and each

and every mark or space length falls within the range of 2 Tw to 8 Tw. This coding method is also applicable to even a situation where a signal of 9 Tw, for example, is intentionally inserted as a sync signal. The mark length classifier **201** shown in FIG. **2** classifies the code lengths of the marks to be made into the four groups of 2T, 3T, 4T and 5T or more. If the code length **n** is 5T or more, the mark length classifier **201** divides (n-1) by the divisor of two (i.e., performs a remainder calculation). By using such a mark length classification signal, the marks and spaces of the write code sequence can be classified into ones that are even-number-of-times as long as the detection window width **Tw** and ones that are odd-number-of-times as long as the detection window width **Tw**. In this preferred embodiment, the divisor is supposed to be two for the sake of simplicity. However, this does not impose any limitation on how to classify the mark lengths. Thus, three or any other greater divisor may be used instead. Also, the mark length classifier **201** of this preferred embodiment operates so as to perform a remainder calculation. However, this never put any limitation on the structure or operation of the mark length classifier **201** but any other classification method may also be adopted.

[0068]

Portion **(b)** of FIG. **7** shows the count signal **205** generated by the counter **200**. The amount of time that has passed since the top of a mark is counted on a detection window width (Tw) basis. The time at which the count signal

goes zero corresponds to the top of a mark or space.

[0069]

Portion **(c)** of FIG. **7** shows a write pulse waveform in making a mark with the 2 Tw length. In this case, the mark making period **305** consists of a single pulse with a length of 0.5 Tw to 1 Tw and a level Pw. The non-mark-making period begins with a period with a length of 1 Tw to 1.5 Tw and a level Pc and then the Pe level is maintained until the next mark making period.

[0070]

Portion **(d)** of FIG. **7** shows a write pulse waveform in making a mark with the 3 Tw length. In this case, the mark making period **305** consists of a single pulse with a length of 1 Tw to less than 2 Tw and a level Pw. The non-mark-making period begins with a period with a length of 1 Tw and a level Pc and then the Pe level is maintained until the next mark making period. It should be noted that in this case, the mark making period is supposed to be longer than that of the 2 Tw long one by at least 0.5 Tw.

[0071]

Portion **(e)** of FIG. **7** shows a write pulse waveform in making a mark with the 4 Tw length. In this case, the mark making period **305** consists of a single pulse with a length of 1.5 Tw to less than 2.5 Tw and a level Pw. The non-mark-making period begins with a period with a length of 1 Tw and a level Pc and then the Pe level is maintained until the next mark making period. It should be noted that in this case, the

mark making period is supposed to be longer than that of the 3 Tw long one by at least 0.5 Tw.

[0072]

Portion **(f)** of FIG. **7** shows a write pulse waveform in making a mark with the 5 Tw length. In this case, the mark making period **305** includes a pulse with a length of 1 Tw and a level Pw, which is followed by a period with a length of 1 Tw and a level Pb and then a period with a length of 1 Tw and a level Pw. The non-mark-making period begins with a period with a length of 1 Tw and a level Pc and then the Pe level is maintained until the next mark making period.

[0073]

After that, in making a mark that is an odd number of times as long as the detection window width Tw, the write pulse waveform during the mark making period includes an additional period with a length of 1 Tw and a level Pb and another additional period with a length of 1 Tw and a level Pw per mark length of 2 Tw in the middle of the mark making period as shown in portions **(h)** and **(j)** of FIG. **7**. The non-mark-making period begins with a period with a length of 1 Tw and a level Pc and then the Pe level is maintained until the next mark making period.

[0074]

Portion **(g)** of FIG. **7** shows a write pulse waveform in making a mark with the 6 Tw length. In this case, the mark making period **305** includes a pulse with a length of 1 Tw and a level Pw, which is followed by a period with a length of 2 Tw

and a level Pb and then a period with a length of 1 Tw and a level Pw. The non-mark-making period begins with a period with a length of 1 Tw and a level Pc and then the Pe level is maintained until the next mark making period.

[0075]

After that, in making a mark that is an even number of times as long as the detection window width Tw, the write pulse waveform during the mark making period includes an additional period with a length of 1 Tw and a level Pb and another additional period with a length of 1 Tw and a level Pw per mark length of 2 Tw in the middle of the mark making period as shown in portion **(i)** of FIG. **7**. The non-mark-making period begins with a period with a length of 1 Tw and a level Pc and then the Pe level is maintained until the next mark making period.

[0076]

In this exemplary write pulse waveform, the shortest Pb level period (i.e., the shortest cooling period) during the mark making period **305** has a length of 1 Tw.

[0077]

Also, in this exemplary write pulse waveform, the Pc level lasts for at least 1 Tw during the non-mark making period.

[0078]

As used herein, the "mark making period" refers to the interval between the leading edge of the first pulse and the trailing edge of the last pulse.

[0079]

Next, FIG. **11** shows write pulse waveforms **1100** through **1107** according to the present invention. In this preferred embodiment, the coder **113** also adopts the coding method in which the (1, 7) code modulation is followed by the NRZI modulation as in portions **(a)** through **(j)** of FIG. **4**, and each and every mark or space length falls within the range of 2 Tw to 8 Tw. This coding method is also applicable to even a situation where a signal of 9 Tw, for example, is intentionally inserted as a sync signal. The mark length classifier **201** shown in FIG. **2** classifies the code lengths of the marks to be made into the four groups of 2T, 3T, 4T and 5T or more. If the code length **n** is 5T or more, the mark length classifier **201** divides (n-1) by the divisor of two (i.e., performs a remainder calculation). By using such a mark length classification signal, the marks and spaces of the write code sequence can be classified into ones that are even-number-of-times as long as the detection window width **Tw** and ones that are odd-number-of-times as long as the detection window width **Tw**. In this preferred embodiment, the divisor is supposed to be two for the sake of simplicity. However, this does not impose any limitation on how to classify the mark lengths. Thus, three or any other greater divisor may be used instead. Also, the mark length classifier **201** of this preferred embodiment operates so as to perform a remainder calculation. However, this never put any limitation on the structure or operation of the mark length classifier **201** but

any other classification method may also be adopted.

[0080]

Portion **(b1)** of FIG. **11** shows the count signal **205** generated by the counter **200**. The amount of time that has passed since the top of a mark is counted on a detection window width (Tw) basis. The time at which the count signal goes zero corresponds to the top of a mark or space.

[0081]

Portion **(b2)** of FIG. **11** shows a sub-count signal **210** generated by the counter **200** and having a phase difference of 180 degrees with respect to the reference signal. The time at which this count signal goes zero has a phase lag of 180 degrees with respect to the top of a mark or a space.

[0082]

Portion **(c)** of FIG. **11** shows a write pulse waveform in making a mark with the 2 Tw length. In this case, the mark making period **305** consists of a single pulse with a length of 0.5 Tw to 1 Tw and a level Pw, and then the Pe level is maintained until the next mark making period.

[0083]

Portion **(d)** of FIG. **11** shows a write pulse waveform in making a mark with the 3 Tw length. In this case, the mark making period **305** consists of a single pulse with a length of 1 Tw to less than 2 Tw and a level Pw, and then the Pe level is maintained until the next mark making period. It should be noted that in this case, the mark making period is supposed to be longer than that of the 2 Tw long one by at least 0.5 Tw.

[0084]

Portion **(e)** of FIG. **11** shows a write pulse waveform in making a mark with the 4 Tw length. In this case, the mark making period **305** includes a pulse with a length of 0.5 Tw and a level Pw, which is followed by a period with a length of 1 Tw and a level Pe and then a period with a length of 0.5 Tw and a level Pw. After that, the level Pe is maintained until the next mark making period. Pw has a pulse width of 0.5 Tw. However, this width may be any value that is equal to or greater than 0.5 Tw. In this case, either or both of the leading and trailing edges of each pulse are synchronous with the sub-count signal. In FIG. **11**, the trailing edge of the first pulse and the leading edge of the second pulse are synchronous with the sub-count signal.

[0085]

Portion **(f)** of FIG. **11** shows a write pulse waveform in making a mark with the 5 Tw length. In this case, the mark making period **305** includes a pulse with a length of 1 Tw and a level Pw, which is followed by a period with a length of 1 Tw and a level Pe and then a period with a length of 1 Tw and a level Pw. Then the Pe level is maintained until the next mark making period.

[0086]

After that, in making a mark that is an odd number of times as long as the detection window width Tw, the write pulse waveform during the mark making period includes an additional period with a length of 1 Tw and a level Pe and

another additional period with a length of 1 Tw and a level Pw per mark length of 2 Tw in the middle of the mark making period as shown in portions **(h)** and **(j)** of FIG. **11**. Then the Pe level is maintained until the next mark making period.

[0087]

Portion **(g)** of FIG. **11** shows a write pulse waveform in making a mark with the 6 Tw length. In this case, the mark making period **305** includes a pulse with a length of 1 Tw and a level Pw, which is followed by a period with a length of 2 Tw and a level Pe and then a period with a length of 1 Tw and a level Pw. Then the Pe level is maintained until the next mark making period.

[0088]

After that, in making a mark that is an even number of times as long as the detection window width Tw, the write pulse waveform during the mark making period includes an additional period with a length of 1 Tw and a level Pe and another additional period with a length of 1 Tw and a level Pw per mark length of 2 Tw in the middle of the mark making period as shown in portion **(i)** of FIG. **11**. Then the Pe level is maintained until the next mark making period.

[0089]

In this exemplary write pulse waveform, the shortest Pe level period (i.e., the shortest cooling period) during the mark making period **305** has a length of 1 Tw.

[0090]

Also, in this exemplary write pulse waveform, the Pc

level lasts for at least 1 Tw during the non-mark making period.

[0091]

As used herein, the "mark making period" refers to the interval between the leading edge of the first pulse and the trailing edge of the last pulse.

[0092]

In some of the preferred embodiments described above, the levels Pc and Pb are supposed to be two different power levels. Alternatively, these levels Pc and Pb may be set equal to each other.

[0093]

Next, FIG. **12** shows write pulse waveforms **1200** through **1207** according to the present invention. In this preferred embodiment, the coder **113** also adopts the coding method in which the (1, 7) code modulation is followed by the NRZI modulation as in portions **(a)** through **(j)** of FIG. **4**, and each and every mark or space length falls within the range of 2 Tw to 8 Tw. This coding method is also applicable to even a situation where a signal of 9 Tw, for example, is intentionally inserted as a sync signal. The mark length classifier **201** shown in FIG. **2** classifies the code lengths of the marks to be made into the four groups of 2T, 3T, 4T and 5T or more. If the code length **n** is 4T or more, the mark length classifier **201** divides (n-1) by the divisor of two (i.e., performs a remainder calculation). By using such a mark length classification signal, the marks and spaces of

the write code sequence can be classified into ones that are even-number-of-times as long as the detection window width **Tw** and ones that are odd-number-of-times as long as the detection window width **Tw**. In this preferred embodiment, the divisor is supposed to be two for the sake of simplicity. However, this does not impose any limitation on how to classify the mark lengths. Thus, three or any other greater divisor may be used instead. Also, the mark length classifier **201** of this preferred embodiment operates so as to perform a remainder calculation. However, this never put any limitation on the structure or operation of the mark length classifier **201** but any other classification method may also be adopted.

[0094]

Portion **(b1)** of FIG. **12** shows the count signal **205** generated by the counter **200**. The amount of time that has passed since the top of a mark is counted on a detection window width (Tw) basis. The time at which the count signal goes zero corresponds to the top of a mark or space.

[0095]

Portion **(b2)** of FIG. **12** shows a sub-count signal **210** generated by the counter **200** and having a phase difference of 180 degrees with respect to the reference signal. The time at which this count signal goes zero has a phase lag of 180 degrees with respect to the top of a mark or a space.

[0096]

Portion **(c)** of FIG. **12** shows a write pulse waveform in making a mark with the 2 Tw length. In this case, the mark

making period **305** consists of a single pulse with a length of 1 Tw and a level Pw. The non-mark-making period begins with a period with a length of 1 Tw and a level Pc and then the Pe level is maintained until the next mark making period.

[0097]

Portion **(d)** of FIG. **12** shows a write pulse waveform in making a mark with the 3 Tw length. In this case, the mark making period **305** consists of a single pulse with a length of 2 Tw and a level Pw. The non-mark-making period begins with a period with a length of 1 Tw and a level Pc and then the Pe level is maintained until the next mark making period. It should be noted that in this case, the mark making period is supposed to be longer than that of the 2 Tw long one by at least 0.5 Tw.

[0098]

Portion **(e)** of FIG. **12** shows a write pulse waveform in making a mark with the 4 Tw length. In this case, the mark making period **305** includes a pulse with a length of 1 Tw and a level Pw, which is followed by a period with a length of 1 Tw and a level Pb and then a period with a length of 1 Tw and a level Pw. The non-mark-making period begins with a period with a length of 1 Tw and a level Pc and then the Pe level is maintained until the next mark making period.

[0099]

After that, in making a mark that is an even number of times as long as the detection window width Tw, the write pulse waveform during the mark making period includes an

additional period with a length of 1 Tw and a level Pb and another additional period with a length of 1 Tw and a level Pw per mark length of 2 Tw in the middle of the mark making period as shown in portions **(g)** and **(i)** of FIG. **12**. The non-mark-making period begins with a period with a length of 1 Tw and a level Pc and then the Pe level is maintained until the next mark making period.

[0100]

Portion **(f)** of FIG. **12** shows a write pulse waveform in making a mark with the 5 Tw length. In this case, the mark making period **305** includes a pulse with a length of 1 Tw and a level Pw, which is followed by a period with a length of 2 Tw and a level Pb and then a period with a length of 1 Tw and a level Pw. The non-mark-making period begins with a period with a length of 1 Tw and a level Pc and then the Pe level is maintained until the next mark making period.

[0101]

Portion **(h)** of FIG. **12** shows a write pulse waveform in making a mark with the 7 Tw length. In this case, the mark making period **305** includes a pulse with a length of 1 Tw and a level Pw, which is followed by a period with a length of 1.5 Tw and a level Pb, a period with a length of 1 Tw and a level Pw, and then a period with a length of 1.5 Tw and a level Pb. The non-mark-making period begins with a period with a length of 1 Tw and a level Pc and then the Pe level is maintained until the next mark making period. In this case, either or both of the leading and trailing edges of each intermediate

pulse are synchronous with the sub-count signal. In FIG. **12**, the leading and trailing edges of the second pulse are synchronous with the sub-count signal.

[0102]

After that, in making a mark that is an odd number of times as long as the detection window width Tw, the write pulse waveform during the mark making period includes an additional period with a length of 1 Tw and a level Pb and another additional period with a length of 1 Tw and a level Pw per mark length of 2 Tw in the middle of the mark making period as shown in portion **(j)** of FIG. **12**. The non-mark-making period begins with a period with a length of 1 Tw and a level Pc and then the Pe level is maintained until the next mark making period.

[0103]

In this exemplary write pulse waveform, the Pc level lasts for at least 1 Tw during the non-mark making period.

[0104]

As used herein, the "mark making period" refers to the interval between the leading edge of the first pulse and the trailing edge of the last pulse.

[0105]

In some of the preferred embodiments described above, the levels Pe, Pb and Pc are supposed to be the same power level. Alternatively, these levels Pe, Pb and Pc may be different from each other.

[0106]

Next, an example of adaptive mark compensation will be described with reference to the accompanying drawings. A high-density optical write operation sometimes causes write interference in which mark edges shift depending on the writing conditions. To prevent the write signal from being deteriorated by such interference, adaptive mark compensation may be carried out.

[0107]

The adaptive mark compensation means a compensation operation of changing the top incidence points or pulse widths of the laser beam according to the length of the given mark, i.e., whether the length of the mark is 2T (2Tm), 3T (3Tm), 4T (4Tm) or 5T or more (≧5Tm), as shown in FIG. **8**.

[0108]

FIG. **8** shows exemplary adaptive mark compensation in a situation where the write power is represented by binary values.

[0109]

By shifting dTtop and Ttop with respect to the beginning of the mark and also shifting Tlp or dTlp with respect to the end of the recording mark according to the code length of the recording mark, among other parameters described above, the edge shifting at the beginning and end of the mark can be minimized and good signal quality is realized.

[0110]

FIG. **9** shows exemplary adaptive mark compensation in a situation where the write power is represented by four values.

[0111]

By shifting dTtop and Ttop with respect to the beginning of the mark and also shifting dTe with respect to the end of the recording mark according to the code length of the recording mark, among other parameters described above, the edge shifting at the beginning and end of the mark can be minimized and good signal quality is realized. Although the write power is supposed to be represented by four values in this example, the same mark compensation is equally applicable to even a situation where three values are used by setting Pb =Pc.

[0112]

The magnitude of shift that can be caused by the write compensation may be defined by a very small step (of Tw/16, for example) with respect to the reference clock signal using a delay line, for instance.

[0113]

Also, the write compensation may be started either from a point in time on the fundamental waveform responsive to the count signal or another point in time responsive to the sub-count signal.

[0114]

In the fundamental waveform of this preferred embodiment, each pulse width and the widths of a period with the bottom power level and a period with the cooling power level in each mark making period are supposed to be at least equal to 1 T. However, after the write compensation has been done, each

pulse for a mark of any of various lengths preferably has a width of at least 0.5 Tw. In that case, the writing conditions can be relaxed without being affected by the laser response speed so much.

[Brief Description of Drawings]

[0115]

[FIG. **1**]

Shows an overall configuration for an information recorder according to the present invention.

[FIG. **2**]

Shows a configuration for the write processing system of the present invention.

[FIG. **3**]

Shows how the write processing system works in the present invention and in the prior art.

[FIG. **4**]

Shows an exemplary set of write pulse waveforms for a write processing system according to the present invention.

[FIG. **5**]

Shows write pulse waveforms for a conventional write processing system.

[FIG. **6**]

Shows another exemplary set of write pulse waveforms for the write processing system of the present invention.

[FIG. **7**]

Shows still another exemplary set of write pulse waveforms for the write processing system of the present

invention.

[FIG. **8**]

Shows how adaptive mark compensation can be done according to the present invention.

[FIG. **9**]

Shows how adaptive mark compensation can be done according to the present invention.

[FIG. **10**]

Shows a configuration for a conventional write processing system.

[FIG. **11**]

Shows yet another exemplary set of write pulse waveforms for the write processing system of the present invention.

[FIG. **12**]

Shows yet another exemplary set of write pulse waveforms for the write processing system of the present invention.

[Description of Reference Numerals]

[0116]

110 laser

111 laser driver

112 write waveform generator

113 coder

117 optical disk

119 reference clock generator

122 read data

126 write code sequence

127 write data

128 reference clock signal

129 write processing system

200 counter

201 mark length classifier

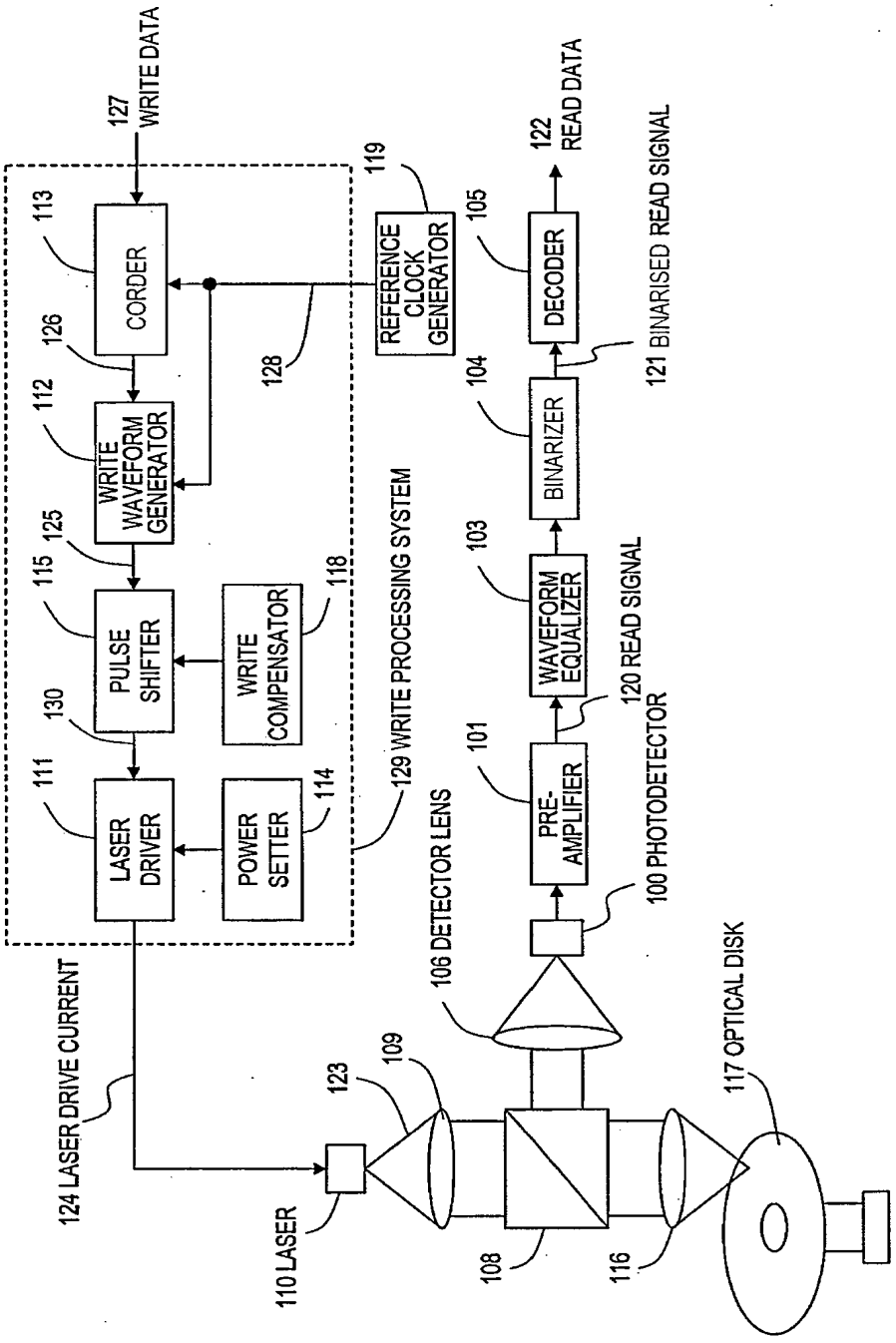
202 write waveform table

204 mark length classification signal

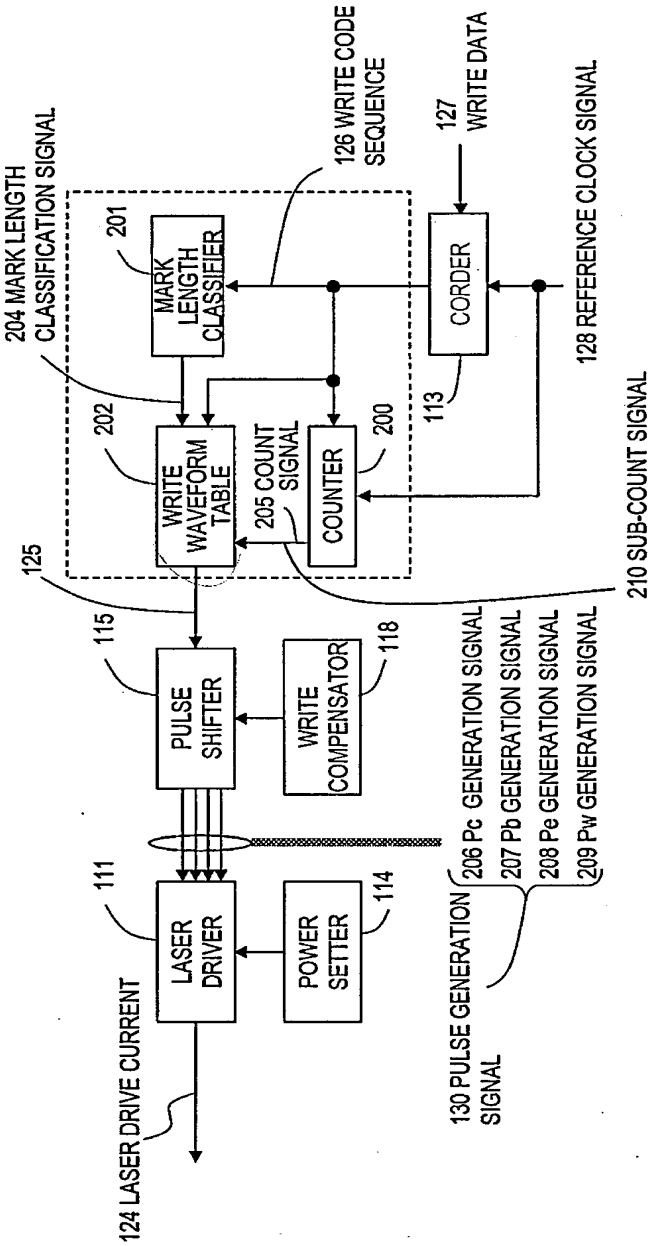
305 mark making period

[Name of Document] Drawings

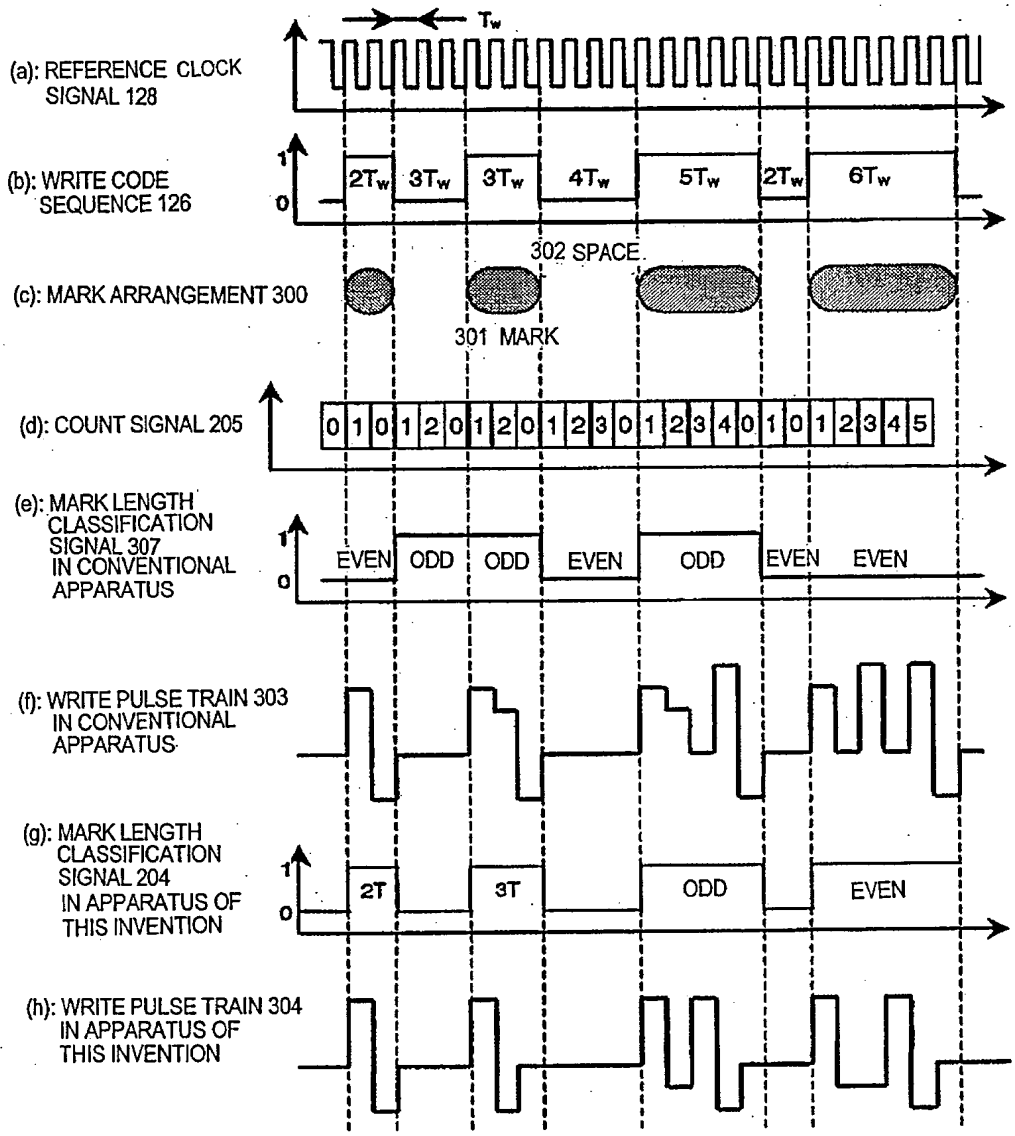
[Fig.1]



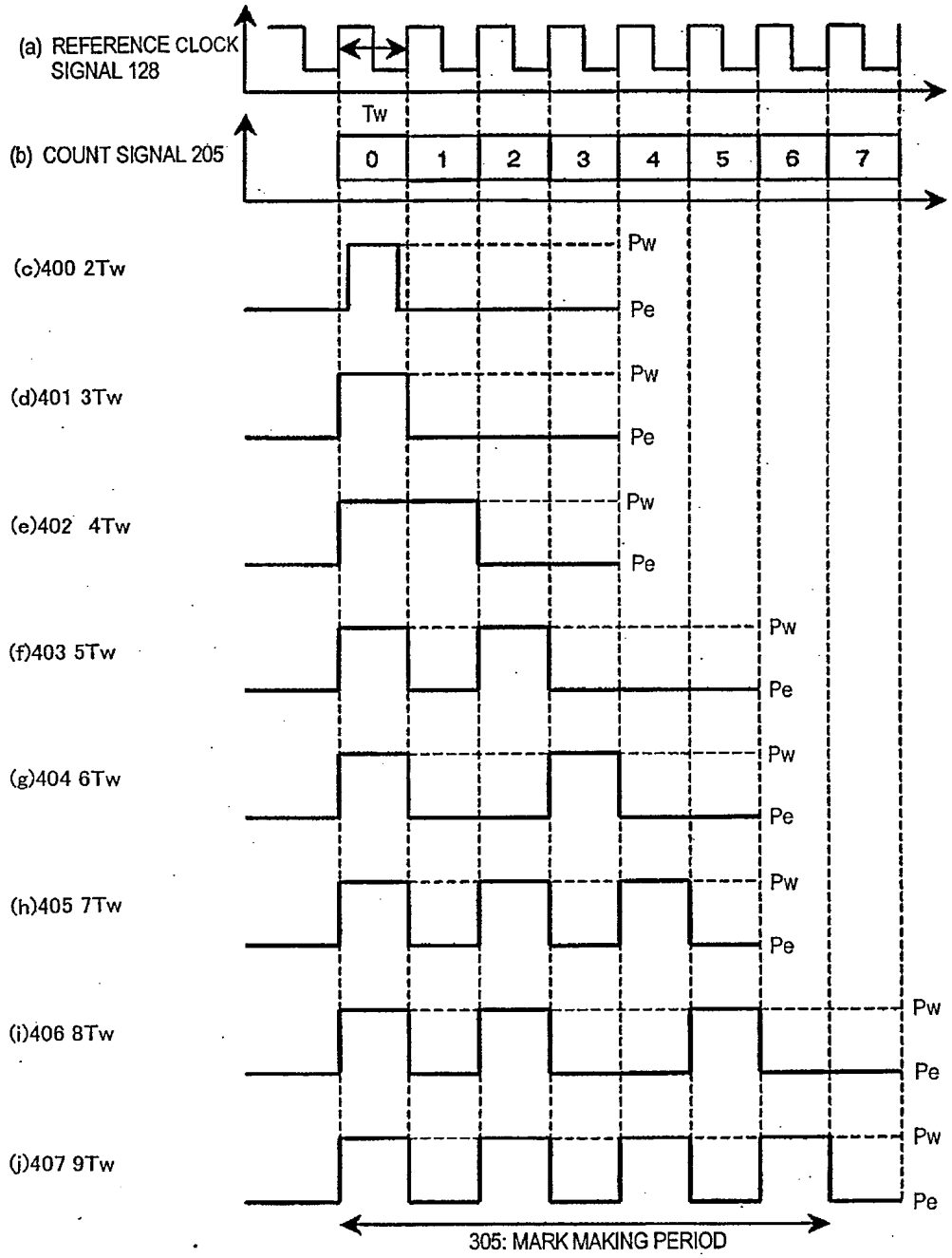
[Fig.2]


204 MARK LENGTH CLASSIFICATION SIGNAL
126 WRITE CODE SEQUENCE
127 WRITE DATA
128 REFERENCE CLOCK SIGNAL
201
MARK LENGTH CLASSIFIER
CORDER
202
WRITE WAVEFORM TABLE
205 COUNT SIGNAL
COUNTER
200
113
210 SUB-COUNT SIGNAL
125
115
PULSE SHIFTER
WRITE COMPENSATOR
118
111
LASER DRIVER
POWER SETTER
114
206 Pc GENERATION SIGNAL
207 Pb GENERATION SIGNAL
208 Pe GENERATION SIGNAL
209 Pw GENERATION SIGNAL
130 PULSE GENERATION SIGNAL
124 LASER DRIVE CURRENT

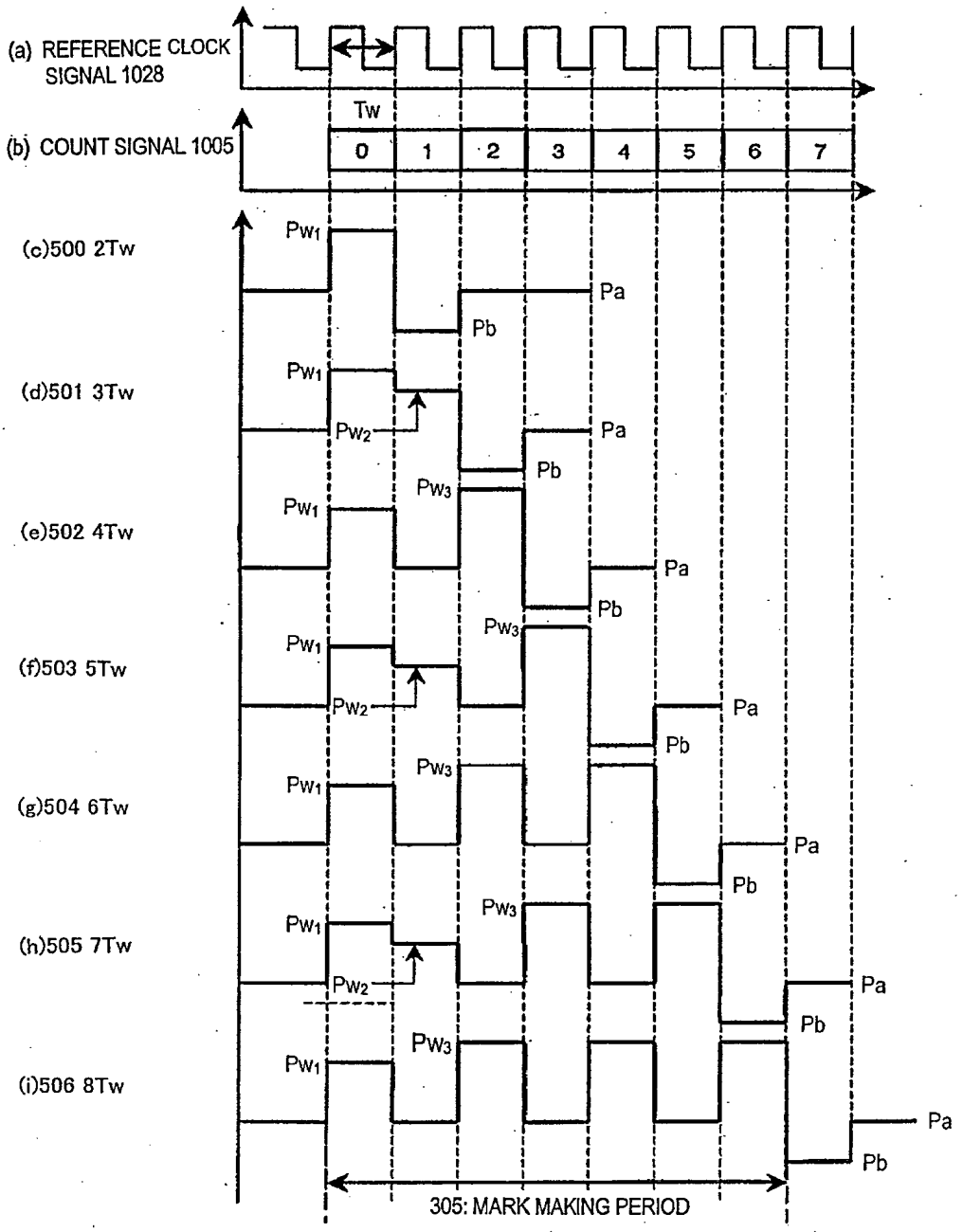
[Fig.3]


Tw
(a): REFERENCE CLOCK SIGNAL 128
(b): WRITE CODE SEQUENCE 126
1
0
2Tw
3Tw
3Tw
4Tw
5Tw
2Tw
6Tw
302 SPACE
(c): MARK ARRANGEMENT 300
301 MARK
(d): COUNT SIGNAL 205
0 1 0 1 2 0 1 2 0 1 2 3 0 1 2 3 4 0 1 0 1 2 3 4 5
(e): MARK LENGTH CLASSIFICATION SIGNAL 307 IN CONVENTIONAL APPARATUS
EVEN
ODD
ODD
EVEN
ODD
EVEN
EVEN
(f): WRITE PULSE TRAIN 303 IN CONVENTIONAL APPARATUS
(g): MARK LENGTH CLASSIFICATION SIGNAL 204 IN APPARATUS OF THIS INVENTION
2T
3T
ODD
EVEN
(h): WRITE PULSE TRAIN 304 IN APPARATUS OF THIS INVENTION

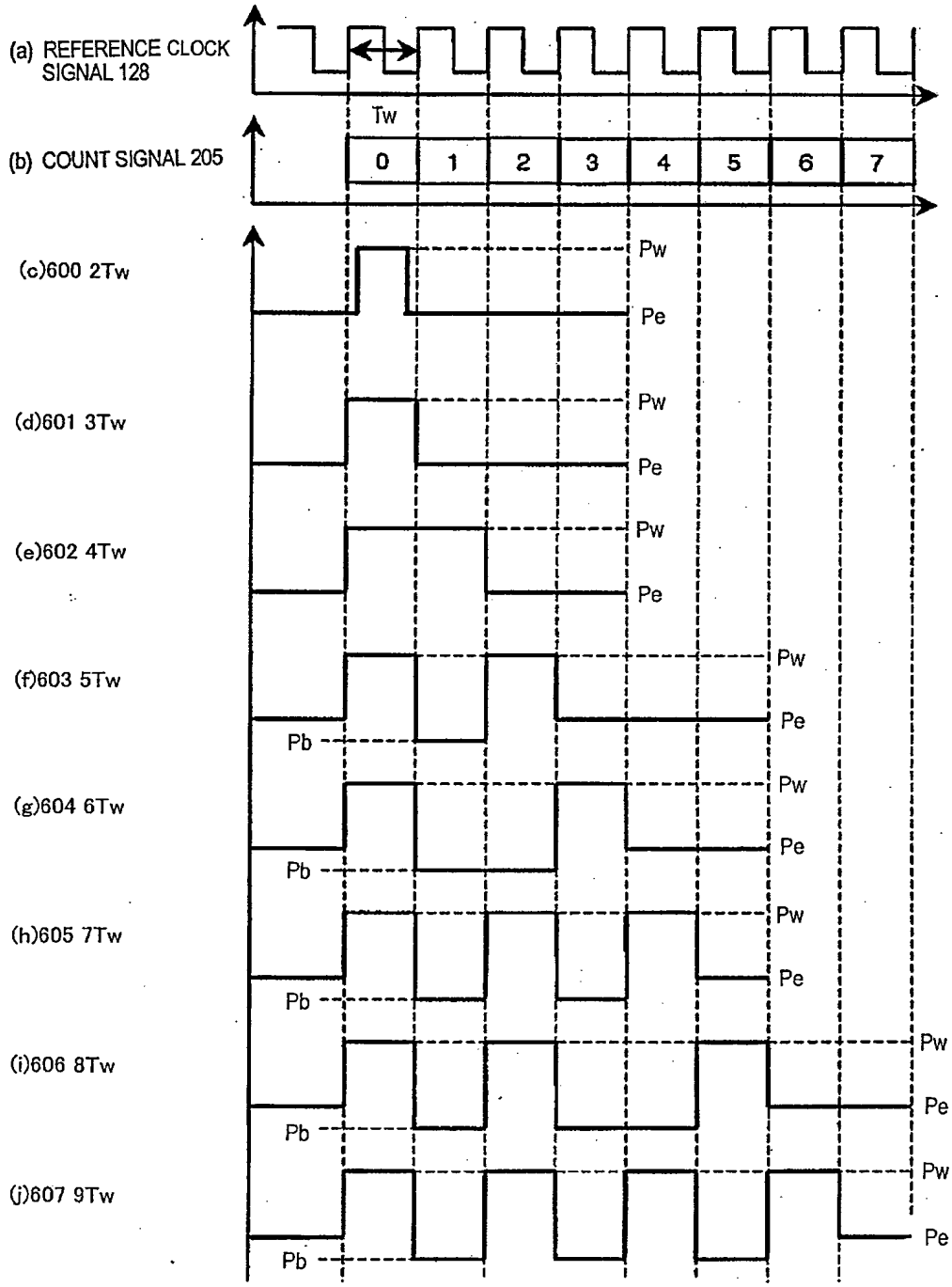
[Fig.4]


(a) REFERENCE CLOCK SIGNAL 128
Tw
(b) COUNT SIGNAL 205
0
1
2
3
4
5
6
7
(c)400 2Tw
(d)401 3Tw
(e)402 4Tw
(f)403 5Tw
(g)404 6Tw
(h)405 7Tw
(i)406 8Tw
(j)407 9Tw
Pw
Pe
305: MARK MAKING PERIOD

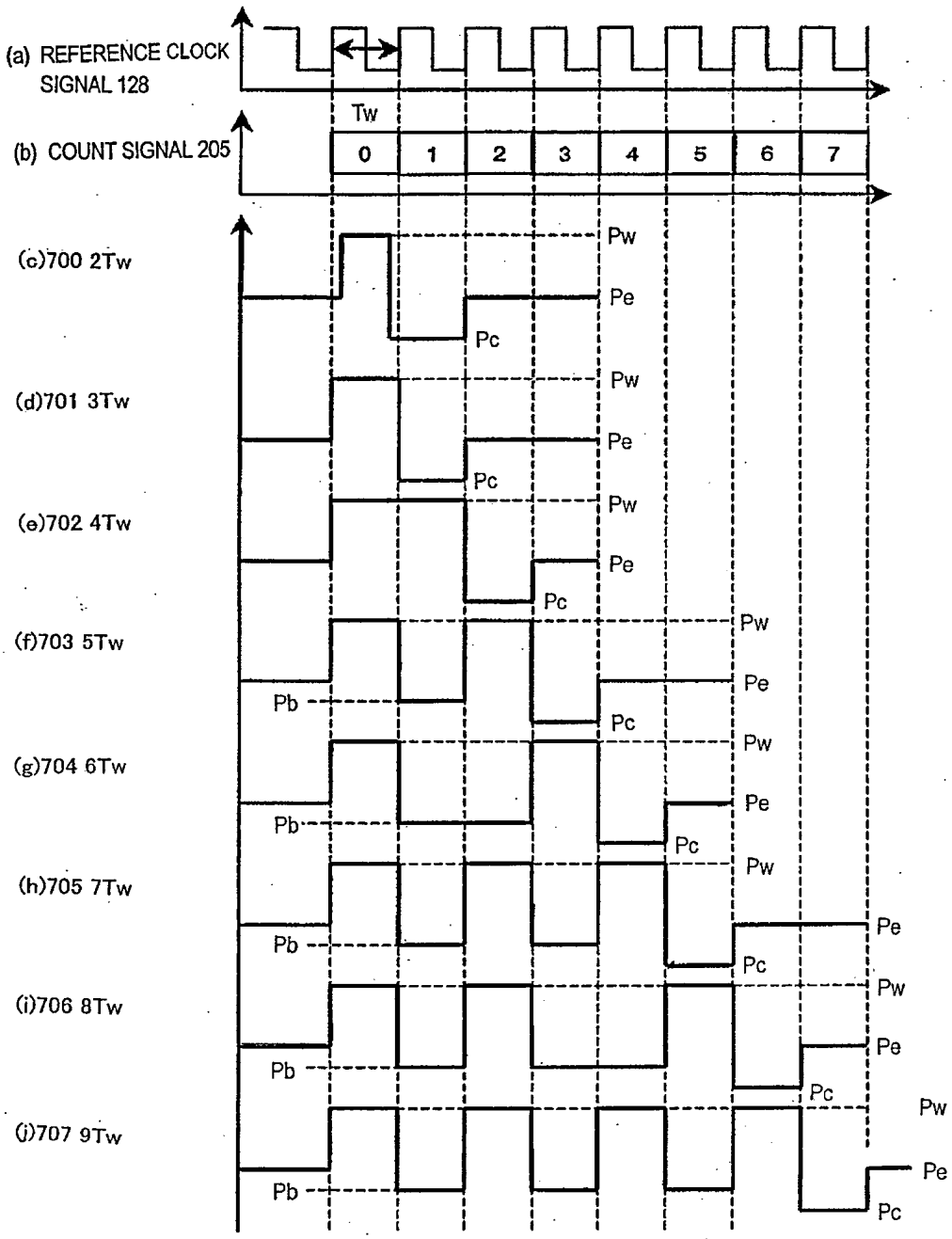
[Fig.5]


(a) REFERENCE CLOCK SIGNAL 1028
Tw
(b) COUNT SIGNAL 1005
0
1
2
3
4
5
6
7
(c)500 2Tw
(d)501 3Tw
(e)502 4Tw
(f)503 5Tw
(g)504 6Tw
(h)505 7Tw
(i)506 8Tw
Pw1
Pw2
Pw3
Pa
Pb
305: MARK MAKING PERIOD

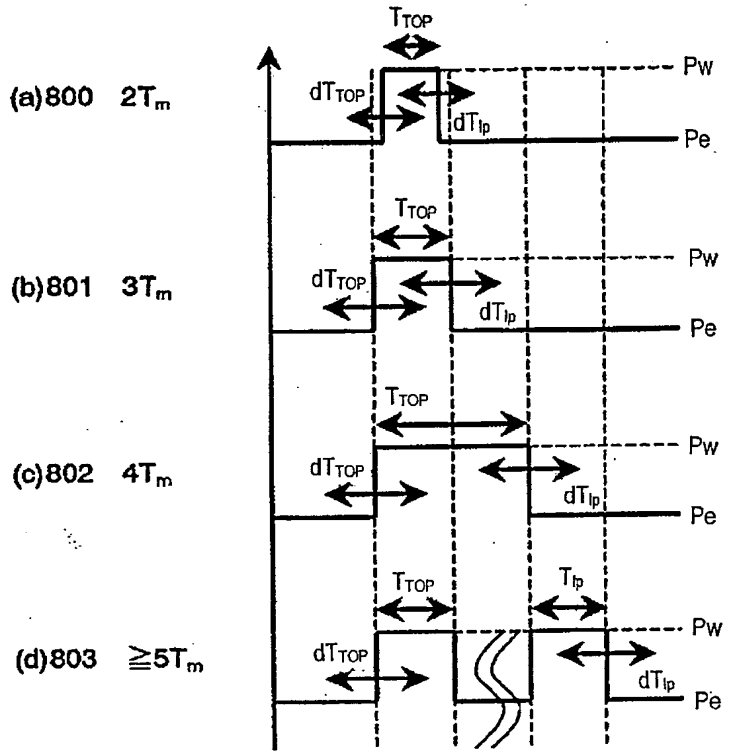
[Fig.6]


(a) REFERENCE CLOCK SIGNAL 128
Tw
(b) COUNT SIGNAL 205
0
1
2
3
4
5
6
7
(c)600 2Tw
(d)601 3Tw
(e)602 4Tw
(f)603 5Tw
(g)604 6Tw
(h)605 7Tw
(i)606 8Tw
(j)607 9Tw
Pw
Pe
Pb

[Fig.7]


(a) REFERENCE CLOCK SIGNAL 128
Tw
(b) COUNT SIGNAL 205
0
1
2
3
4
5
6
7
(c)700 2Tw
(d)701 3Tw
(e)702 4Tw
(f)703 5Tw
(g)704 6Tw
(h)705 7Tw
(i)706 8Tw
(j)707 9Tw
Pw
Pe
Pc
Pb

[Fig.8]



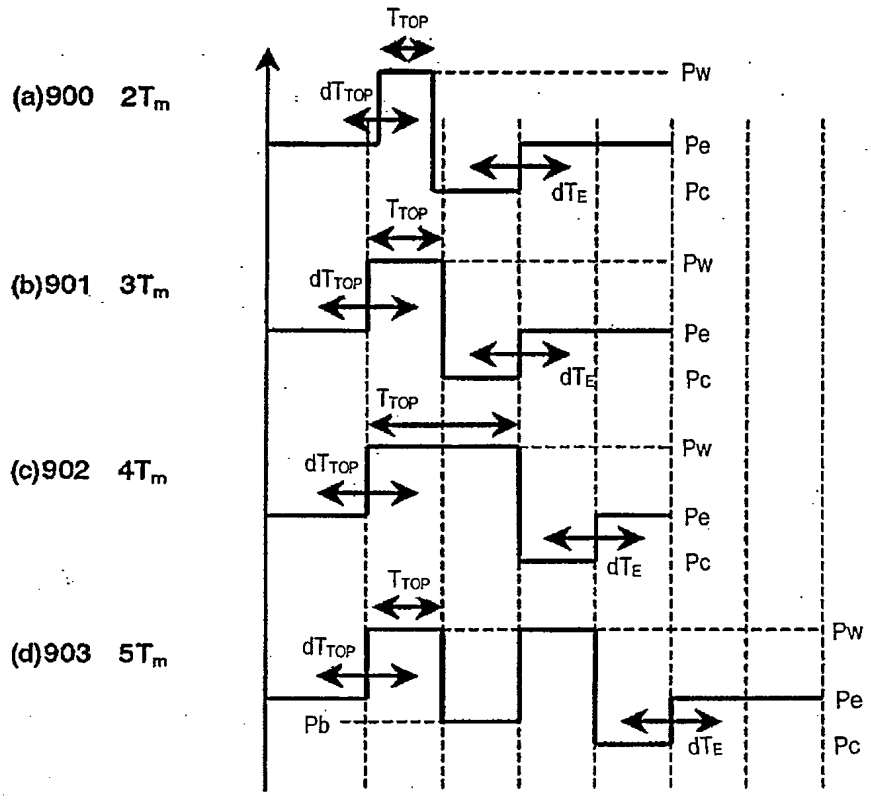
FIRST PULSE INCIDENCE POINT

	2T	3T	4T	≧5T
T_{TOP}				
dT_{TOP}				

LAST PULSE INCIDENCE POINT

	2T	3T	4T	≧5T
T_{lp}				
dT_{lp}				

[Fig.9]



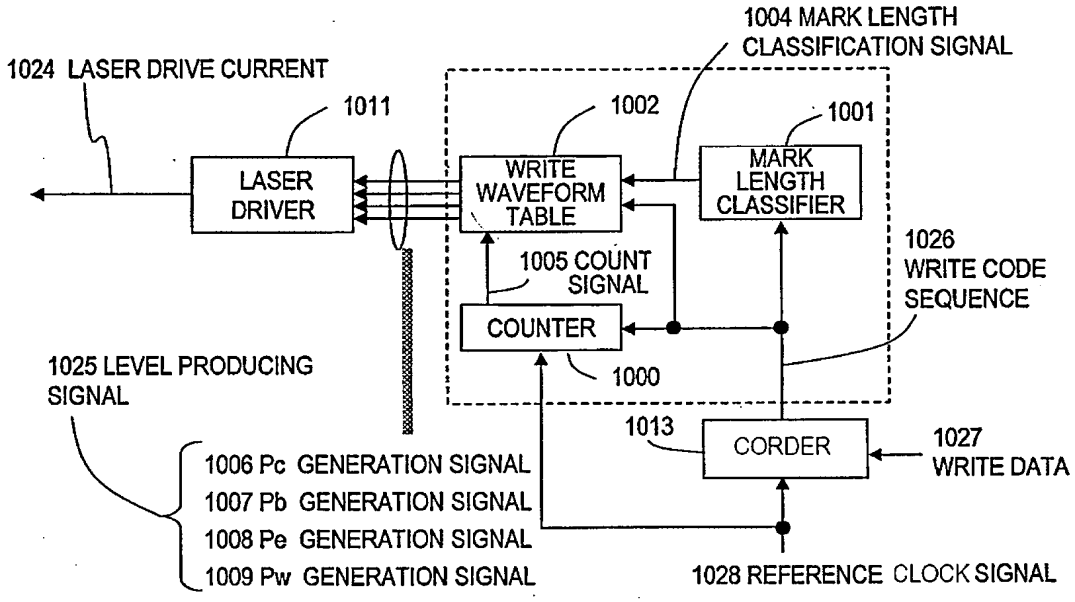
FIRST PULSE INCIDENCE POINT

	2T	3T	4T	≧5T
T_{TOP}				
dT_{TOP}				

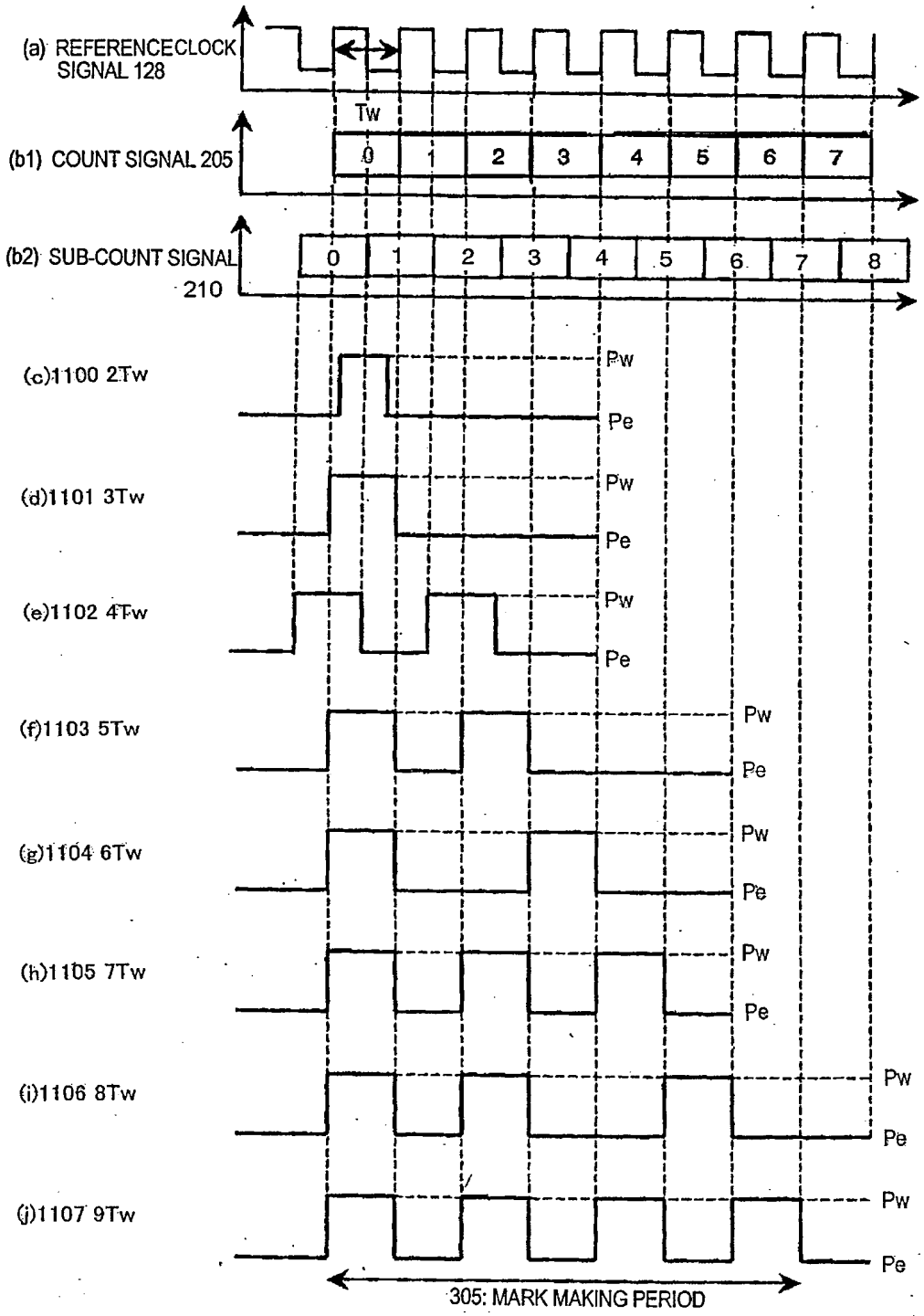
COOLING PULSE INCIDENCE POINT

	2T	3T	4T	≧5T
T_E				

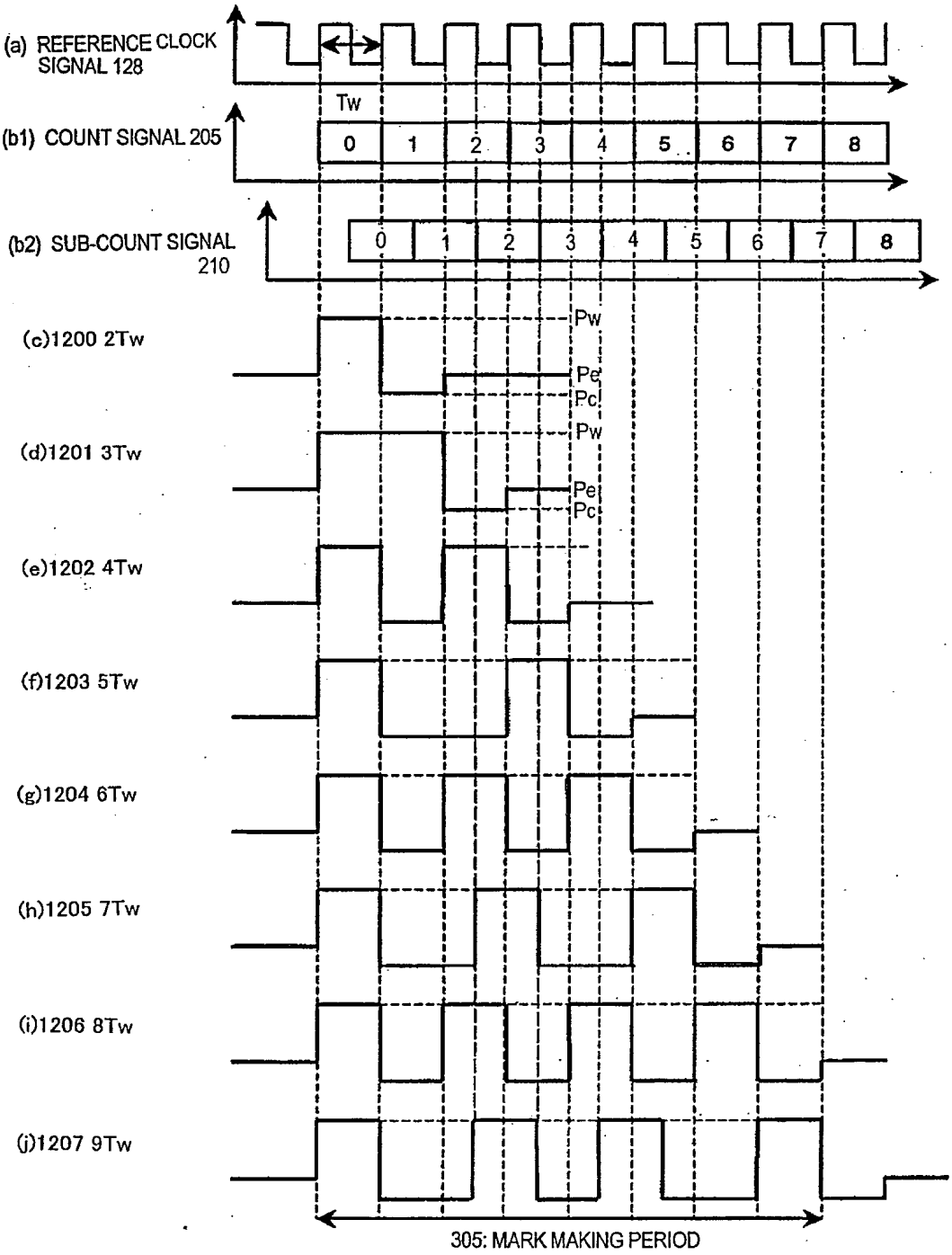
[Fig.10]


1004 MARK LENGTH CLASSIFICATION SIGNAL
1024 LASER DRIVE CURRENT
1011
1002
1001
LASER DRIVER
WRITE WAVEFORM TABLE
MARK LENGTH CLASSIFIER
1026 WRITE CODE SEQUENCE
1005 COUNT SIGNAL
COUNTER
1000
1025 LEVEL PRODUCING SIGNAL
1013
CORDER
1027 WRITE DATA
1006 Pc GENERATION SIGNAL
1007 Pb GENERATION SIGNAL
1008 Pe GENERATION SIGNAL
1009 Pw GENERATION SIGNAL
1028 REFERENCE CLOCK SIGNAL

[Fig.11]


(a) REFERENCE CLOCK SIGNAL 128
Tw
(b1) COUNT SIGNAL 205
0 1 2 3 4 5 6 7
(b2) SUB-COUNT SIGNAL 210
0 1 2 3 4 5 6 7 8
(c)1100 2Tw
(d)1101 3Tw
(e)1102 4Tw
(f)1103 5Tw
(g)1104 6Tw
(h)1105 7Tw
(i)1106 8Tw
(j)1107 9Tw
Pw
Pe
305: MARK MAKING PERIOD

[Fig.12]


(a) REFERENCE CLOCK SIGNAL 128
Tw
(b1) COUNT SIGNAL 205
0 1 2 3 4 5 6 7 8
(b2) SUB-COUNT SIGNAL 210
0 1 2 3 4 5 6 7 8
(c)1200 2Tw
(d)1201 3Tw
(e)1202 4Tw
(f)1203 5Tw
(g)1204 6Tw
(h)1205 7Tw
(i)1206 8Tw
(j)1207 9Tw
Pw
Pe
Pc
305: MARK MAKING PERIOD

[Name of the Document] ABSTRACT

[Abstract]

[Problem] To make a mark accurately and quickly with an optical disk recorder/player for writing information on an optical disk medium by applying laser power and making a region with a different physical property from a non-recorded portion thereof.

[Means for Solving the Problem] To drive the laser more easily during writing and allow the disk medium an ample cooling time, means for driving energy generating means is provided to change energies and number of pulses applied during a mark making period according to the mark length such that the interval between two arbitrary variation points of the energy applied per unit time while information is being written becomes equal to or greater than, or approximately a natural number of times as long as, the detection window width. As a result, the read/write operation can be done more quickly with more reliability, and a high-performance optical disk recorder/player with a reduced size and increased capacity can be provided at a lower cost.

[Selected Figure] FIG. **1**